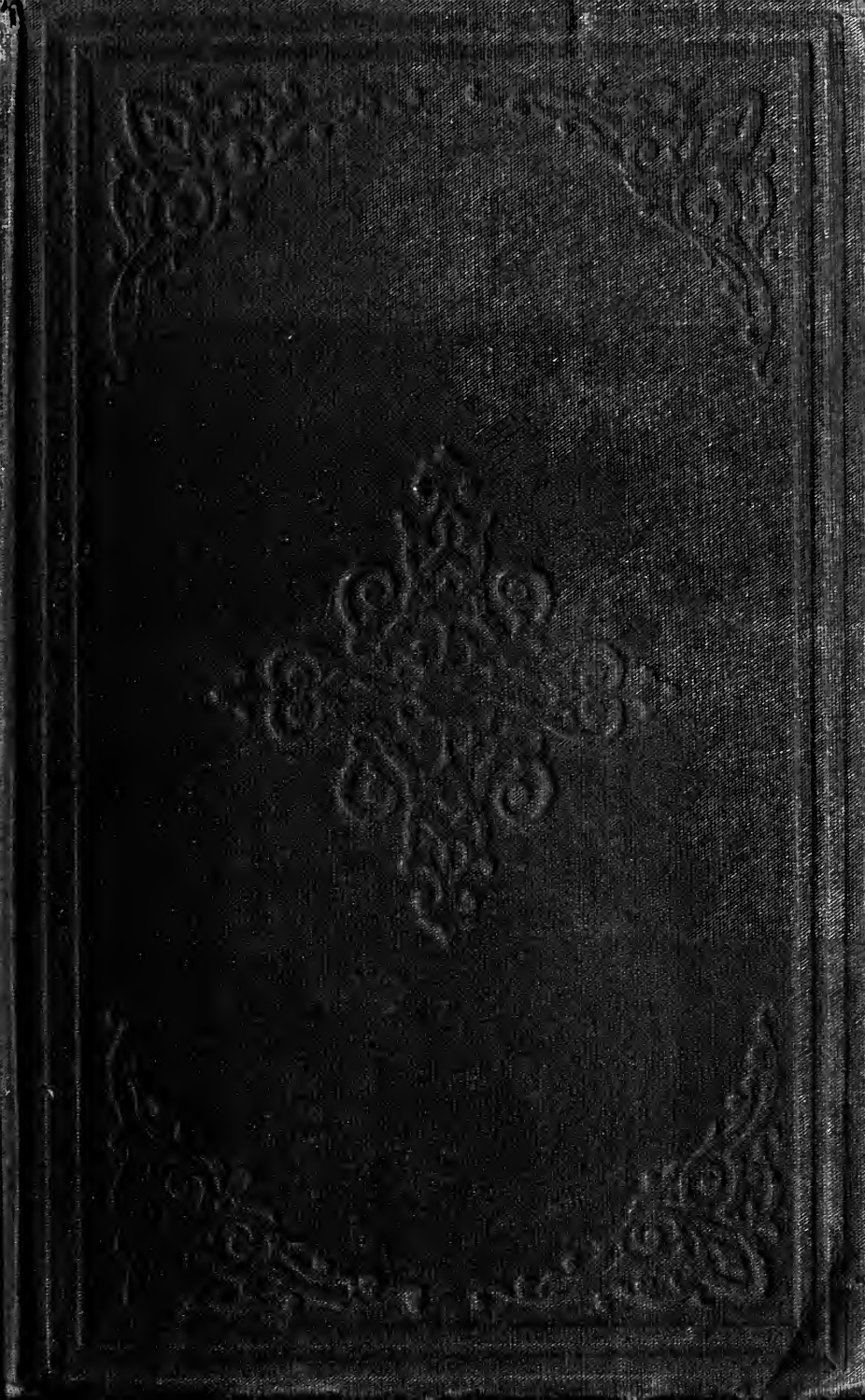

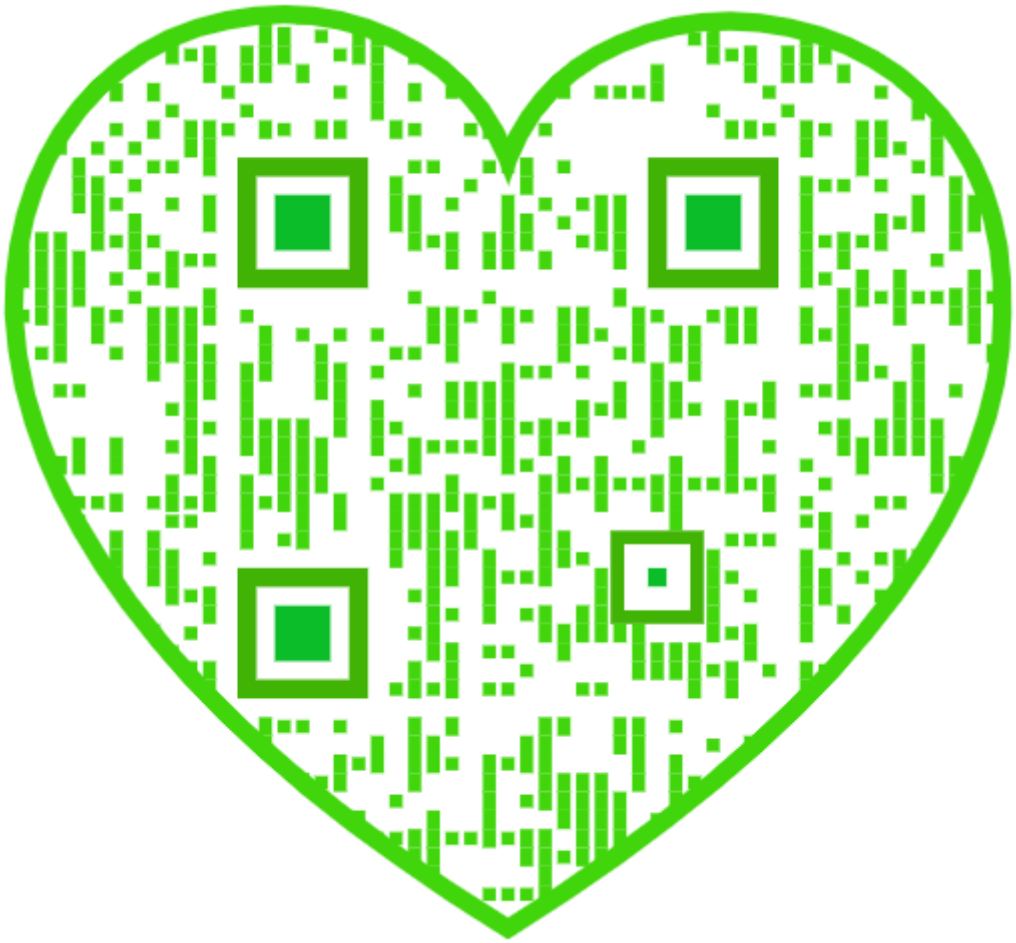

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MODERN

AMERICAN LOCOMOTIVE ENGINES;

THEIR

DESIGN, CONSTRUCTION AND MANAGEMENT.

A PRACTICAL WORK FOR PRACTICAL MEN.

BY

EMORY EDWARDS, M. E.,

AUTHOR OF "A CATECHISM OF THE MARINE STEAM ENGINE," "MODERN AMERICAN MARINE ENGINES, BOILERS AND SCREW PROPELLERS," "PRACTICAL STEAM ENGINEER'S GUIDE," ETC., ETC.

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112336

PREFACE.

THE following pages have been compiled at the earnest solicitation of a number of correspondents residing in different sections of the country, who have read the previous works of the writer's on steam engineering, evidently with both interest and profit. Many have asked: "Why not get up a book on the locomotive, and complete the series?" and this book is the result of those suggestions. There necessarily comes a time in the life of every locomotive engineer, particularly when old age and its attendant infirmities begin to make themselves felt, that he fain would resign the throttle valve, and leave the foot-board to younger and stronger men.

To do this and find employment suited to his taste and experience, he turns, naturally, to the shops. To prepare himself for a responsible position, with a salary at least equal to that received while running on the road, he should devote his leisure hours to study, to observation of each and every advance made in the construction of locomotives; and by every other means come-at-able to keep himself "posted," and abreast of the times. The means of so doing are within the reach of every man who desires to improve himself. Good books and newspapers on steam engineering abound, and can be had for a mere trifle

compared with their value. Every engineer should have a library—every live, intelligent, progressive one has one—and that library can be filled with valuable books and papers without their owner denying himself any of the necessaries of life. Colburn, Norris, Forney, Roper, Reynolds, Hoxie, Smith, and other eminent men have given their time and talents "to make the rough way smooth" for their less fortunate fellow-craftsmen, and be it said to their credit, they have not lived nor labored in vain.

To those worthy seekers after "more light," who, after perusing these pages, wish to continue their studies, he would recommend, in addition to the works of the engineers above mentioned, for a *theory* of the steam engine, "A Text Book on the Steam Engine," by T. M. Goodeve; and for a *history* of the steam engine from the time of Hero, 200 B. C., to the present day, "The Growth of the Steam Engine," by Prof. R. H. Thurston. As regards newspapers, "*The American Machinist*," "*The Mechanical Engineer*," and the *Scientific American Supplement*," are worthy of all praise and support.

In conclusion, the writer will add that he claims no *originality* for this work; *original* books on this subject are scarce and hard to find; it is, on the contrary, a compilation of valuable papers on locomotive engineering, by some of the most advanced, most talented, and most scientific engineers that the country has yet produced, *and hence all the more valuable.*

It requires no argument to prove that the combined

ideas, skill and experience of such eminent men in the profession as Frank C. Smith, Lewis F. Lyne, Chas. A. Hague, Wm. H. Hoffman, W. Barnet Le Van, Wm. J. Williams, Melville Clemens, John W. Hill, F. B. Allen, Angus Sinclair, and others, are of far more value than that of any one man, be his skill and experience what it may, and the writer is indebted to them and the newspapers mentioned, and particularly "*The American Machinist*," for the valuable information found in these pages.

Should the perusal of this volume assist one worthy man or boy to better his condition in life, the only object of the writer will be fully accomplished.

EMORY EDWARDS.

Baltimore, Md.
309 Carrollton Avenue,
(Lafayette Square),
August 10, 1883.

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INTRODUCTION.

STEAM.

THE most prominent of the properties possessed by steam are its high expansive force, its property of condensation by an abstraction of its temperature, its concealed or undeveloped heat, and the inverted ratio of its pressure to the space which it occupies. Steam is the result of a combination of water with a certain amount of heat; and the expansive force of steam arises from the absence of cohesion between and among the particles of water. Heat universally expands all matter within its influence, whether solid or fluid; but in a solid body it has the cohesion of the particles to overcome, and this so circumscribes its effects that in cast-iron, for instance, a rate of temperature above the freezing point sufficient to melt it, causes an extension of only about one-eighth of an inch in a foot. With water, however, a temperature of 212°, or 180° above the freezing point, and which is far from red-heat, converts it into steam of 1700 times its original bulk or volume.

All bodies may exist in either one or all of three different states, namely, the solid state, the liquid state, and the aeriform state, or state of vapor. Water, for

example, may exist as ice, liquid, and steam; and the condition which it assumes depends on its pervading temperature. Steam cannot mix with air while its pressure exceeds that of the atmosphere, and it is this property, with that which makes the condition of a body dependent on its temperature, that explains the condensing property of steam. In a cylinder once filled with steam of a pressure of 15 pounds or more to the square inch, all air is excluded. Now, as the existence of the steam depends on its temperature, by abstracting that temperature, which may be done by immersing the cylinder in cold water or cold air, the contained steam assumes the state due to the reduced temperature, and this state will be water. And, as the water cannot occupy the volume which it did under its former temperature, it follows that its reduction in volume must remain a vacuum. A cylinder, therefore, filled with hot steam, may be condensed by an abstraction of its heat, and a vacuum will be produced in the cylinder, with a few drops of water at the bottom, which may be pumped out by an air-tight pump, leaving the vacuum perfect. When this principle is employed in removing the atmospheric pressure opposed to the back of a piston in a steam engine, such an engine is termed a condensing engine: and in such engines more work may be done with the same pressure of steam than by a non-condensing engine, as the absence of the weight of the air on the negative pressure on the back of the piston is equivalent to a positive pressure on the other side, and contributes by so

much to the useful effect of the engine. Locomotive engines, however, and most American stationary engines, discharge their steam without condensing, and to overcome the atmospheric resistance they carry higher steam; they are therefore called high-pressure engines. The next property of steam which we have mentioned is that of its latent or concealed heat. An unknown amount of latent heat exists in every element in nature; thus, iron becomes hot by merely hammering it on an anvil; air gives off heat enough to light a fire by being compressed into a syringe, and so on. The beating of the iron does not create the heat which it excites, neither does the compressing of the air; they both merely develop the heat, which must have a previous existence. In these examples the heat which existed is freed by the motion communicated, and we have no means of knowing its amount; but the latent heat of steam, though showing no effects on the thermometer, may be as easily known as the sensible or perceivable heat. To show this property of steam by experiment, place an indefinite amount of water in a closed vessel, and let a pipe, proceeding from its upper part, communicate with another vessel, which should be open, and, for convenience of illustration, shall contain just 5½ lbs. of water at 32°, or just freezing. The pipe from the closed vessel must reach nearly to the bottom of the open one. By boiling the water contained in the first vessel until steam enough has passed through the pipe to raise the water in the open vessel to the boiling point, 212°, we shall find the

weight of the water contained by the latter to be 6½ lbs. Now this addition of one pound to its weight has resulted solely from the admission of steam to it, and this pound of steam, therefore, retaining its own temperature of 212°, has raised 5½ lbs. of water 180°, or an equivalent of 990°; and including its own temperature, we have 1202°, which it must have possessed at first. The sum of the latent and sensible heat of steam is in all cases nearly constant, and does not vary much from 1200°. It is from this property of steam that it becomes of such essential service in heating buildings; one square foot of superficial surface of cast-iron steam pipe will keep 200 cubic feet of air at a genial summer heat; but a square foot of the surface of a bar of iron, of the same perceivable temperature, would scarcely start the frost on the windows on a cold morning. If a known volume of steam of a certain pressure be made to occupy but one-half that volume, its elastic force will be doubled; or, in other words, the same pressure is exerted within one-half the original capacity. By pressure we mean the initial elastic force of the steam, which is always the same in equal weights of steam, and which can only act with greater intensity of pressure by restricting the area exposed to its action. In fact, it is an established law of steam, and of all elastic fluids generally, that the pressure which they exert is inversely as the space occupied; or, to be more precise, it is very nearly so. The elasticity of steam increases with an increase in the temperature applied, but not in the same ratio. If steam is gen-

erating from water at a temperature which gives it the same pressure as the atmosphere, an additional temperature of 38° will give it the pressure of two atmospheres; a still further addition of 42° gives it the tension of four atmospheres; and with each successive addition of temperature, of between 40° and 50°, the pressure becomes doubled. It is well for the student of the steam engine to know the reason of this effect, and we will endeavor to explain it. We have already said that there is no cohesion among the particles of fluids, but there is, however, an attraction between all matter in nature. The action of heat in generating steam has to overcome this attraction among the particles of the water, and likewise the gravity of the water itself. As the water becomes rarefied by heat, and, either in its natural state or as steam, occupies a greater volume, this attraction is diminished, and also the weight or gravity of the water; hence an additional rate of temperature does not have to contend with the same resistance as the temperature which preceded it, and is, therefore, enabled to produce greater effects in the generation of steam. Among a variety of facts and notes relative to the nature of steam, we select the following: If water be boiled in an open vessel, no temperature greater than that for the boiling point, which for fresh water is 212°, can be produced in it. All surplus heat which may be applied passes off in the steam. If the vessel be closed, and the steam as it is formed be retained within it, the temperature may be raised, and retained in the steam. If the steam, as

it is formed, is allowed to accumulate in the boiler, its pressure on the water-level makes an increased temperature necess ry to continue its production. Steam in itself is invisible, and becomes visible only upon condensation, as when a jet is discharged in the open air; its loss of temperature causes it to condense, and we see it in the form of a vapory cloud. In treating of steam, the term heat is understood as expressing its sensible heat, while the term caloric provides for the expression of every conceivable existence of temperature. To explain the theory of ebullition, or boiling liquids, we will observe that in metals, heat is communicated by the conducting property they possess · but in liquids it is communicated by a circulation of particles. If heat be applied to the bottom and sides of a vessel containing water, that portion of the water in contact with the heated metal becomes heated and rarefied, and consequently lighter than the rest, whereby it ascends to the surface, gives off its vapor, becomes cooled, and in consequence of becoming heavier, descends again, to become heated, rise, and descend as before, and to maintain these operations in a constant succession so long as the heat is applied. This action is performed in vertical planes, and if the heat be applied above the bottom of the vessel, the water below that point will receive but little heat, and can never be made to boil. An established relation must exist between the temperature and elasticity of steam; in other words, water at 212° must be under the pressure of the steam naturally resulting from that

temperature; and so at any other temperature. If this natural pressure on the surface of the water be removed without a corresponding reduction in the temperature, a violent ebullition at the water-level is the immediate result. Thus, suppose the entire steam-room in a boiler to be six cubic feet, and the contents of the cylinder which it supplies to be two cubic feet; at each stroke of the piston one-third of all the steam in the boiler is discharged, and the surface of the water is consequently relieved from one-third of the pressure upon it before that stroke. The temperature remains the same, but as it does not bear the natural relation to this diminished pressure, it causes the water to boil violently, and produces foaming. Foaming is the cause of which priming, or working water along with the steam into the cylinders, is the effect. Provision must therefore be made in all boilers, that they may have a large extent of steam-room compared with the cylinders which they supply. Another result attending the formation of steam is, that when an engine is in operation and working off a proper supply of steam, the water-level in the boiler artificially rises, and shows by the gauge-cocks a supply greater than that which really exists. This is owing to the steam forming in the water and rising in bubbles to the surface, and displacing by its bulk the amount of water indicated by the rise at the gauge-cocks. As the production of steam under the same temperature cannot continue under an increased pressure, it follows that when the discharge of steam is

stopped, and its entire pressure is thrown on the surface of the water, steam is no longer generated, and the water takes its natural level. At whatever point in a boiler steam be taken, there is a determination of water to that point, which is occasioned by the sudden reduction in the pressure, owing to the withdrawal of the steam. This is the case with all boilers having steam domes with throttle in the same; and it was for this reason that, on certain new engines lately constructed, the steam-dome was omitted, and in its stead a steampipe, perforated on its upper side, was extended the whole length of the boiler, occupying the position usually given to the steam-pipe in ordinary locomotives. The object of this was to take the steam alike from all parts of the steam-room of the boiler, so that no rise of water should result at any one point.

CHAPTER I.

STEAM ENGINEERING.

THE observation and experience of the writer* have confirmed him in the opinion that there exists among so-called "practical men," a great need of "scientific education" on subjects directly pertaining to the business they may be engaged in.

The very foundation of science is the faculty of *calling things by their right names;* for by such a method only, can one be perfectly understood and answered accordingly.

These lines are written in the exacting light of Webster's dictionary, and it is suggested to all who may read them with the view of knowing just what they mean, to read with a dictionary close at hand, and if its occasional use will *start* readers in a habit of thoroughly comprehending whatever they give their attention to, an important step towards a scientific education will have been taken.

Science is simply "a positive statement of truth, established by observation and experiments," and can as well be applied to the operations of every-day work, as to the most intricate branches of human inquiry; in other words, there is one *best way* to perform every

* Hague.

operation in the different trades, varying, of course, with surrounding circumstances; and a comprehension of these best ways constitutes the science of the trade.

Art, on the other hand, is "the power of performing certain actions;" so it would seem then, for a man to be successful at his calling, he must acquire both science and art, or the knowledge of "how to do a thing," and the skill to "do it."

Some of the deductions in this chapter are based upon the theory of the "Mechanical Equivalent" of heat; a theory that has probably been established as firmly as any natural law, although some controversy was indulged in but a short time ago.

According to the above theory, heat is simply "a mode of motion," that is, an influence by which motion is produced among the atoms of substances; this *motion*, however, is imperceptible, the *heat* only being detected by the sense of feeling.

A comprehensive idea of heat would be, that it is a means employed by a *natural force* to produce motion; *why* the force should operate in the manner in which it does, is beyond the bounds of the present writing; indeed the "physical constitution of heat" is one of the mysteries not yet solved by science.

When a piece of iron is heated, then (scientifically speaking) the minute atoms of which it is composed are set in motion to a degree corresponding to the intensity of the force influencing them. If the motion is sufficiently increased, the iron passes from solid tc liquid, or melts. The motion may be still further

increased until the substance of the iron combines with the oxygen of the air, combustion takes place, the heat is set free, the iron is destroyed, and there remain gases and cinders.

For convenience of comparison and measurement heat is divided into "units," in the same manner that distance is divided into inches.

Careful experiments by different men and at different times, have resulted in a standard of value for each unit of heat; this standard is "772 foot pounds," that is, the dynamic energy inherent in one unit of heat is equivalent to the dynamic energy required to lift 772 pounds one foot high, or one pound 772 feet high, friction not considered; this amount of work is considered to be the "mechanical equivalent" of one unit of heat.

Before proceeding further, a few definitions will be in order:

Force: Is any action that can be measured by weight alone.

Dynamics: Is a positive statement of truth, established by observation and experiment, in relation to forces in motion.

Dynamic energy: Is the mechanical power or work produced by forces in motion.

And now we come directly to our subject:

Steam engineering is a branch of the science and art of *developing dynamic energy from heat.*

The subject might be divided into several distinct branches, but the extent of this chapter is necessarily limited to a general treatment.

Heat having been produced by combustion of fuel, the first step is to provide some means for conveying it (heat) to where it can be placed under conditions favorable to the development of dynamic energy, or power.

The means employed in this case is water, and the instrument by which the power is made available for practical use is the Steam Engine; in these lines the well-known reciprocating engine, only, will be considered.

Water having absorbed heat, assumes the gaseous form, or becomes steam, and in this state acts as the vehicle by which the heat is transported from boiler to engine; but it must be borne in mind that it is not the steam but *heat* that does the work.

Before proceeding further, it will be well to observe that "dry saturated steam," is steam in which just sufficient heat has been absorbed to evaporate all moisture; its temperature and density (quantity of water) are elements which bear a proportion to each other, corresponding to the pressure.

When an excess of heat has been absorbed, the steam is said to be "superheated," and when a deficiency of heat exists, the steam is termed "wet."

Steam parts with heat, to be converted into effect by the operation of EXPANSION; for if it (steam) were confined in a tight vessel and perfectly protected from loss of heat by radiation, and not allowed to expand, it would possess no other forces than that of its pressure on sides of vessel, and its weight; its weight

would of course be the weight of the water which, having absorbed heat, became steam.

Without regard to loss by friction, radiation, and conduction, the utmost quantity of steam that could be consumed in the production of a certain power, would be when no expansion took place within the cylinder of the engine; in which case the steam would exert only its "force of displacement."

For example: The pressure in boiler is 100 lbs. per inch: induction valves of engine are "set" to admit steam during the whole stroke of piston; then steam will flow into the cylinder in a manner similar to that of water entering a pump; that is, the heat being supplied by fire under the boiler as fast as it passes into the cylinder in the form of steam.

In the above case the heat exerts only its *external* force, or that action measurable by weight alone; and it does so because heat generated in the furnace or boiler, having free communication with the cylinder through the medium of the steam, maintains the full pressure of 100 lbs. per inch throughout, and thus prevents expansion. The force of heat operating in this manner is similar to the force of so much weight acting through space.

An engine under such circumstances would be practically "pumping" the heat from the boiler, without utilizing any of its (heat's) mechanical equivalent.

On the other hand, an extreme towards economy in the use of steam would be, to admit the steam to the cylinder at the boiler pressure and then close the in-

duction valve at a point in the stroke that would cause the steam to expand in a non-condensing engine just down to the pressure of the atmosphere, and in a condensing engine down to the pressure due to the vacuum on exhaust side of piston.

Theoretically, and without regard to certain *counteracting effects* that will be discussed further on, the greater the difference between the pressure at the point of cut-off, and the pressure at the end of the stroke, the greater will be the quantity of heat converted into dynamic energy.

It is the province of the steam engineer to take into consideration the action of *all* natural laws pertaining to his vocation, and arrange his ideas in such a manner that his theory of construction will be adjusted to meet the demands of *every* influence that is exerted during the operation of producing HEAT, and converting its forces into mechanical effect.

The average economic results of the best modern practice are probably not far from 20 per cent. of total "heat value" of fuel; the average of ordinary performance, however, is far short of the above, and some specimens of the engineer's art in daily operation are doubtless so far in the rear, that they are very expensive property to own.

However well designed and constructed a steam engine may be, the full advantage of its merits cannot be realized unless the boiler is of a character and capacity to correspond. There are some boilers made in conformity to principles that render them capable of gen-

erating dry saturated steam, and in some cases superheated steam, but even with such boilers there is a very considerable waste of heat by radiation, absorption, etc.; there is also a comparatively large percentage of the heat of combustion, it will be observed, escapes up the chimney, for the reason that boilers giving off dry or superheated steam are so constructed, that some of the parts forming heating surface come in contact with steam, and of course the heat from the furnace must be considerably higher than that of contained steam, and continue so all the way to uptake, where the remaining heat enters the chimney and is lost; and so it would seem that with the present methods of generating steam, even in the best practice, a large proportion of the heat produced is not utilized: in other words, before the water is evaporated and steam is ready to enter the pipe for conveyance to the engine, the heat value of the fire is practically very materially reduced.

There is also a class of boilers, and doubtless the largest class in daily use, that are so arranged and operated that it is impossible to obtain dry steam from them; the heating surface is badly distributed, and, as a consequence, very little steam is generated at some points, while at others the water absorbs heat so rapidly that the resulting steam, in endeavoring to escape to the surface of the water, finds such crooked or narrow passages, that in forcing its way through them a portion of the water is carried along, and the result is, the steam never gets rid of the water with which it

(steam) becomes over-saturated; this result is assisted by loss of heat, with which the steam unavoidably meets; to add to the general shortcomings, there is, generally, in such boilers, no opportunity for heat in the flues to come in contact with surface situated conveniently for the absorption of such heat by the over-saturated steam.

A steam boiler, to produce economical results, should be constructed and set so as to permit a free combustion of the fuel, and give sufficient volume of space for the hot gases to combine, in a manner calculated to effect the utmost production of heat due to the fuel consumed.

Combustion of fuel is the *chemical combination* of the substance of the fuel with the oxygen of the air; and now, before progressing any further with our subject, it will be desirable to present a few facts in Natural Philosophy.

A mechanical mixture: Is a *composition* in which the ingredients retain their natural properties; steam is a mechanical mixture of heat and water; atmospheric air is an invisible gas, produced by the mechanical mixture of two other gases, viz., oxygen and nitrogen.

A chemical combination: is *an action*, during which certain elements and substances are absorbed and destroyed, in the production of some other element or substance. Heat is a product of the chemical combination of the element oxygen with a combustible substance; and to produce the maximum volume of heat

from a given weight of fuel, it is necessary that a proper quantity of oxygen, and under correct conditions, be admitted to the furnace and combustion chamber.

The maximum rate of heat having been provided for, the surface of the boiler exposed for its operation should be of sufficient extent to allow the necessary time for transmission of heat to the contained water; when the heating surface is insufficient, the heat is certain to be carried through the flues or tubes and into the up-take, before it (heat) can be absorbed to an economical extent.

There must be, also, ample room for the escape of steam to the surface of the water, and after it has passed above the water, it would seem as though it was necessary to bring it (steam) again in contact with some heating surface, to thoroughly complete the evaporation, and even superheat the steam slightly, before it is finally allowed to pass to the engine.

Cases have been known in which the steam was apparently superheated to a considerable degree at the point where it entered the pipe leading to the engine, but, on reaching the steam chest, had relapsed to the temperature due to the pressure, although the pipe was protected from radiation in a manner that would forbid the supposition that heat enough had escaped to make the difference; the facts of the case were most probably, that the extent of heating surface in the boiler was excessive in proportion to the quantity of water, and also very effectively situated, so that the steam, having an exceedingly favorable opportunity for escape to

and above the surface of the water, was generated and passed into the pipe so rapidly that the evaporation was incomplete, although heat in excess of that due to the pressure was carried by the steam, and during the passage through the steam pipe to the engine, sufficient time elapsed to allow the apparent surplus heat to be absorbed by the excess of moisture. With the ordinary horizontal tubular boiler, the production of dry steam is a very difficult task, unless some considerable heat is wasted; for the reason that it would be necessary to operate the boiler as near its capacity as possible, without causing it to prime, and to do this, comparatively "hard firing" would be unadvoidable.

If the steam is not a trifle superheated when leaving the boiler, it is hardly possible for it to be dry at the engine.

Engine cylinders without steam-jackets, when working steam expansively, must necessarily indicate some symptoms of moisture, even when dry or superheated steam is used, because there is no opportunity for additional heat to enter the cylinder after the cut-off valve has closed, and the loss of heat by the iron, resulting from the peculiar effects of expansion of the steam, must be made good from somewhere, and that source is eventually the condensation of a portion of initial steam at the next stroke of the piston.

We may calculate, theoretically, the gross dynamic energy that should be developed from a certain weight of fuel, but the actual operation of the best-known practice must necessarily fall far short of the estima-

tion, unless the boiler and furnaces can be so constructed that there will be absolutely no escape of heat, and the boiler-room and all the appliances thereof, under such conditions, would indicate a temperature corresponding to that due to the weather; there must not, of course, be any heat escaping from the chimney. If we could thus burn fuel and produce steam without the slightest loss of heat whatever, it would only remain to convert it into dynamic energy, until the temperature of the steam was reduced to that of the coolest feed water used during the operation: assuming the feed-water to be at a temperature of 60° Fahr. the steam must be expanded down to that degree, and it (steam) would then indicate a pressure of considerably less than one pound per inch above an absolute vacuum, or about 14.5 pounds per inch below the zero on the ordinary steam pressure gauge.

In order to comprehend the nature of a vacuum, it will be necessary to become thoroughly acquainted with a few facts concerning the air we breathe, and establish such facts so firmly in the mind that they may be referred to as readily as to the letters and figures that form the basis of every-day information. In the first place, the fact must be clearly understood that the air in which we move is simply an invisible gas; the height or depth of this gas or air, reckoned from sea level, has been variously estimated, but it will serve our present purpose to assume it to be 50 miles in a vertical direction from the surface of the sea to the upper surface of this stratum of air.

Now the pressure of water is just its weight bearing upon the surface which supports it: this pressure is in proportion to the depth or height of the water above the supporting surface; water being a fluid, presses in every direction, but the vertical downward pressure is the greatest.

The weight or pressure of the air is of the same nature as that of water, differing from it only in intensity of force. A column of water 2 or 3 feet high exerts a pressure or weight of 1 pound per square inch; a column of air the full height of the atmosphere (50 miles), exerts a pressure or weight, on the earth's surface, varying from about 14 pounds per square inch to over 15 pounds, but the average is assumed to be 14.7 pounds per inch. If we take a hollow air-tight globe, and expel the air from it, the globe will be subjected to a crushing strain of 14.7 pounds per square inch of exterior surface, and the interior space will be in a condition of "vacuum." An absolute vacuum would be produced if all the air could be forced out of the hollow globe.

The pressure gauge, by which the force of steam is indicated, exhibits only the pressure in excess of that due to the air; the completeness with which the air or other gas or vapor is removed from the interior of a vessel or chamber, or, in other words, the quality of the vacuum, is measured by a "vacuum gauge;" the "zero" of the steam guage and "zero" of the vacuum guage exactly coincide, the steam gauge indicating pressure above the air or atmospheric line, while the

vacuum gauge exhibits the pressure below that line, when the steam gauge attached to a boiler indicates a pressure of 100 pounds per inch, the pressure within boiler is actually about 114.7 pounds per inch, but 14.7 pounds of the pressure is balanced by the air outside of the boiler, and the straining pressure is only 100 pounds. In calculating expansion of steam, the pressure required to balance that of the air must be added to the indication of the steam gauge, the same being the total pressure of steam above an absolute vacuum.

In continuing our subject we have to deal not only with the economical expenditure of heat, but quite as much with the ways and means of producing, preserving, and conveying it to the place where it is to do its work. The direct object in view, in this particular branch of the general operation, is to consume the least value of fuel on the grates, and let the least number of heat units escape.

When a man has accepted any certain thing as a fact, it is a law of his nature to endeavor to strain everything of similar nature to it, and to be astonished if the second thing does not strain without breaking. For years it was reasoned that steam, like air and similar gases, was a very bad radiator and absorber of heat, and every experiment in cylinder operation that argued to the contrary was set aside as doubtful, or was most thoroughly gone over and examined to find the "error." But about ten years ago, Prof. Tyndall, after a series of careful and thorough experiments, gave to the world the fact that the vapor of water would absorb and

radiate heat several thousand times more rapidly than dry air would do so. And yet, for years men had known that steam would rush into a condenser and give up its heat so nearly *instantly*, that a sensitive vacuum gauge in full communication with the condenser would give but slight evidence of the transmission of hundreds of heat units through the chamber.

Before reaching a conclusion in regard to the expansion of steam, the engineer is confined to several important questions, and these questions require different answers under different conditions. An investigation to determine the number of volumes to which steam can be profitably expanded, gives rise to sub-investigations to determine the *quality of the steam;* the nature of the valve gear, proportions of steam ports, and other particulars concerning the construction of the intended engine, claim a share of attention. The items of piston speed, rate of reciprocation, weight of the moving parts, etc., etc., enter into the consideration.

The conversion of heat into work during expansion is accompanied by some very curious and interesting incidents, and, like all good things, reacts in a disadvantageous manner when carried too far. The detraction does not come from any cessation of the primary benefit for which expansion is instituted, but from the increase in the power of the evil genius, "condensation," with which the operation is associated, even in its lowest grades. But the two are inseparable, unless certain precautions are taken before expansion begins. The very thing from which the

benefit is derived is the root of the evil referred to, viz., the loss sustained by the expanding steam, of the heat that is converted into work. The mean temperature of the cylinder under ordinary conditions is never up to that of the initial steam, and the higher the ratio of expansion to do a certain value of work (and, consequently, the higher the initial pressure and temperature, and also the shorter the cut-off), the lower the temperature of the cylinder is in proportion.

The obvious reason for this fall in temperature, incidental to the shortening of the cut-off, is, that the expansion curve falls from the point of cut-off nearer vertical at short than at long cuts, and there is proportionately very much more surface exposed to a comparatively "cooler" body of steam in the high than in the low grades. For expansion of ten volumes, the latter half of the curve does not depart very much from a parallel to the atmospheric line, while for four volumes a totally different appearance presents itself, showing that during the former (ten) the cylinder was exposed to a much lower temperature, and for a longer time, than during the latter.

Hence the economy of expansion, and, therefore, the extent to which it is desirable to carry it, depend chiefly upon the success with which the loss of the heat converted is made good. The abstraction of heat, re-evaporation of water set free, and subsequent condensation of initial steam during one cycle, is comparatively insignificant; and if each revolution made good its own losses, no serious harm would follow

But the quantity of moisture accumulates until there is insufficient time during one stroke to evaporate it all. At very short cut-offs the condensation, at the early part of the stroke, is sometimes indicated after the induction valve has closed.

To prevent this cylinder condensation, the most expeditious and perhaps the only methods, are, to either provide means for supplying the cylinder with the heat it loses during the re-evaporation after cut-off (and so keep the iron up to initial temperature), or to furnish the initial steam itself with sufficient extra heat above its saturated temperature to meet the demands made by the cooled cylinder.

Both of the agents pointed out are often used together, and the application is known in technical language as steam jacketing and using superheated steam.

The importance of superheated steam has been long known, but the difficulties surrounding the practice of conveying the heat to the steam, and at the same time controlling the degree of extra temperature, have prevented a very general adoption of the system; but devices are now coming into use aiming to satisfactorily answer all demands. Superheating is now at about the same stage of progress that automatic engines were twenty years ago; and there is very little doubt of its final success with the steam-using public, when its manipulation is made sufficiently practicable to ensure the benefit promised by its advocates. The superheating apparatus must be of a character that can be easily understood and managed by the class of help

that it pays to employ, as attendants for engines and boilers.

Developments are being made which indicate the necessity of the degree of super-heat bearing a specific relation to the grade of expansion, and these developments plainly tell us why the practice of superheating has been unsuccessful by not acquiring a sufficiently high temperature, and hence of not much benefit in some cases; and also why, in other cases, it has failed by indulgence to excess, and thereby burned out the packing and injured the cylinder and valves.

It would seem that the degree of super-heat must be as closely looked after as the pressure of steam in the boiler; and its relation to the grade of expansion suggests the idea of regulating the super-heater automatically, to correspond to the automatic control of the cut-off.

As has been previously intimated, steam economy exclusively is not the only desideratum to be looked for in steam engines. The extent to which it is carried must depend upon the relative expense incurred in effecting the expansion, and also upon the means which must be employed in utilizing it under the conditions which accompany the undertaking in hand.

Assuming that we can manage to expand the steam and avoid loss of heat to the utmost extent compatible with the laws of radiation, absorption, etc., and the use of iron cylinders, one of the first obstacles to be encountered is the fact that the energy expended by the steam is very far from being uniform. At the begin-

ning of the stroke the impulse is greatly in excess of all demands, while during the latter part of the stroke the pressure on the piston falls far short of that required to drive the load. Hence, if we *must* use expansion, a suitable *reservoir* must be furnished to receive this excess of energy, and be so related to the general mechanism that the effect will be uniform throughout the stroke. This reservoir may consist either of the ponderous moving parts of the engine, such as the balance wheel, cross head, connecting rod, etc., etc.—the inertia of these parts absorbing the surplus energy during the early part of the stroke, and giving it out again gradually as the pressure falls during the latter portion—or, by the use of compound engines, the pressure may be distributed by the use of a receiver of some magnitude between the cylinders, working steam in conjunction with each other, in which case the inertia of moving parts is of little or no importance in the matter of distribution.

CHAPTER II.

THE PROPERTIES OF WATER.*

WATER was supposed to be an element until Priestley, late in the eighteenth century, discovered that when hydrogen was burned in a close vessel water was deposited on its sides. (It has been shown that the combustion of hydrogen requires eight parts, by weight, of oxygen, and vapor of water is the result.)

It was not, however, until Cavendish and Lavoisier investigated water that its chemical composition was determined.

The several conditions of water are usually stated as the solid, the liquid, and the gaseous. Two conditions are covered by the last term, and water should be understood as capable of existing in four different conditions—the solid, the liquid, the vaporous, and the gaseous. At and below 32° Fahr. water exists in the solid state, and is known as ice. According to Prof. Rankine, ice at 32° has a specific gravity of .92. Thus a cubic foot of ice weighs 57.45 lbs.

When water passes from the solid to the liquid state, heat is required for liquefaction sufficient to elevate the temperature of one pound of water 143° Fahr. This is termed the latent heat of liquefaction. According to M. Person, the specific heat of ice is .504, and the latent heat of liquefaction 142.65.

* Hill.

From 32° to 39° the density of water increases; above the latter temperature the density diminishes.

Water is said to be at its maximum density at 39°, and under pressure of one atmosphere weighs, according to Berzelius, 62.382 lbs. per cubic foot. The following formulæ may be used to estimate the weight of water at any other temperature:

$$D = \frac{2\,D'}{\frac{T+461}{500} + \frac{500}{T+461}}$$

where D=weight of cubic foot of water at temperature T′, and D′=weight of cubic foot of water at maximum density. Desired the weight of a cubic foot of water at a temperature of 60°.

$$\frac{62.381 \times 2}{\frac{60+461}{500} + \frac{500}{60461}} = \frac{124.762}{2.0016} = 62.331$$

Water is said to vaporize at 212° Fahr., and pressure of one atmosphere (14.7 lbs.), but Faraday has shown that vaporization occurs at all temperatures from absolute zero, and that the limit to vaporization is the disappearance of heat. Dalton obtained the following experimental results on evaporation below the boiling temperature:

Temp.	Rate of Evaporation.	Barometer.
212	1.00	29.92
180	.50	15.27
164	.33	10.59
152	.25	7.93
144	.20	6.488
138	.17	5.565

From this, the general law is deduced that the rate of surface evaporation is proportioned to the elastic force of the vapor.

Thus, suppose two tanks of similar surface dimensions and open to the atmosphere, one containing water maintained constantly at 212° Fahr., and the other containing water at 144° Fahr.

Then for each pound of water evaporated in the last tank, five pounds will be evaporated in the first tank.

It should be understood that the law of Dalton holds good only for dry air, and when the air contains a vapor having an elastic force equal to that of the vapor of the water, the evaporation ceases.

The boiling point of water depends upon the pressure. Thus at one atmosphere (14.7 lbs. 29.92″ barometer) the temperature of ebullition is 212°. With a partial vacuum, or absolute pressure of one pound (2.037″ of mercury) the boiling point is 101.4° Fahr.

Upon the other hand, if the pressure be 74.7 lbs. absolute (60 lbs. by the gauge), the temperature of evaporation becomes 307° Fahr.

The relations of temperatures and pressure have been made the subject of special investigation from the time of Watt, down to the celebrated experiments of Regnault, which have been accepted as conclusive so far as they extended.

The relations of pressure and density, however, have not been determined by experiment. Messrs. Fairbairn and Tate have investigated this problem and deduced a formula, but late experience has shown that

while the Fairbairn and Tate formula is perhaps the best of its kind, it cannot be accepted as correctly stating the relations of pressure and density. (Van Nostrand's Magazine, June, 1878.)

The vaporous condition of water is limited to saturation. That is to say, when water has been converted by heat into vapor (steam), and when this vapor has been furnished with latent heat sufficient to render it anhydrous, the vaporous condition ends, and the gaseous state begins. Superheated steam is water in the gaseous state.

The temperature of the gaseous state of water, like that of the vaporous, depends upon the imposed pressure. Under pressure of one atmosphere, water exists in the solid state at and below 32° Fahr.; from 32° to 212° it exists in the liquid state; at and above 212° in the vaporous state; and above saturation in the gaseous state.

It has been stated that water boils at 212°, but MM. Magnus and Donney have shown that, when water is freed of air, it may be elevated in temperature to 270° before evaporation takes place.

The specific heat of water under the several conditions is as follows:

Solid	.504
Liquid	1.000
Vaporous	.475 to 1.000
Gaseous	.475

CHAPTER III.

ECONOMY OF FUEL.*

THE perfect combustion of fuel is a matter of great interest, and any means tending to that end will have a national value. While the steam engine of the present exceeds in economy that of the past, and while steam boilers are made in our day which will evaporate more water per pound of coal than was thought possible a generation ago, neither result can be attributed to the superior manner in which the coal itself is burned. Whether we go into a steam boiler fire-room that was constructed twenty years ago, or one where the whole plant is only a few weeks old, precisely the same means for burning the coal will be found. Once in a while some one who claims that he has solved the problem of how to produce perfect combustion makes his appearance, and claims that a trial only is necessary to convince the most skeptical. The economizing of fuel has been a problem which some of the most intelligent men of the world have grappled with in the most earnest manner during the last fifty years, and with varying success. The chemistry of combustion, received and accepted as a truth, seems a very simple matter, but when reduced to practice, is found to be

* Williams.

one of the most difficult of problems. Perfect combustion in furnaces used in the arts, or for mechanical purposes, according to the views of those of known intelligence and recognized as authorities the world over, has never yet been accomplished; nor, for various causes, can we avail ourselves of the whole of the heat produced from a given quantity of any kind of fuel.

Coals from different localities vary in their component parts. Taking, for the convenience of illustration, anthracite coal: the average quantity of fixed carbon from ten collieries in Schuylkill county, Pennsylvania, is 85 per cent., and that of sulphur one-fourth of one per cent., hydrogen not being present in any of them. If it be assumed that 100 pounds of anthracite coal contain 85 pounds of fixed carbon, it would require 332.88 pounds of oxygen for its conversion into carbonic acid, thereby effecting perfect combustion. Now 332.88 pounds of oxygen equal 2943.11 cubic feet, to furnish which 1027.70 pounds, or 13424.5 cubic feet, of atmospheric air will be required. Sulphur being present, demands its equivalent of oxygen; and small as the quantity is, it requires a further supply of air, if only to become sulphurous acid, and if it remains only as such, is an extinguisher of combustion, while its presence in any form tends to help defeat the object aimed at. Omitting the sulphur from the calculation, the product will be 2943.11 cubic feet carbonic gas, and 10481.39 cubic feet of uncombined nitrogen; that is, if we had an absolutely pure, unadulterated, dry atmosphere — something which never exists; conse-

quently, some idea of the magnitude of the task of accomplishing perfect combustion may be arrived at

We thus see that each pound of coal requires 138 cubic feet of air for its perfect combustion; that is, to convert the carbon into carbonic acid. Just in proportion as the quantity is deficient is combustion imperfect, while a surplus quantity is a change of evils, since all the air, which passes through a fire without giving up its oxyen to the fuel, will abstract heat and give nothing in return. In all likelihood, in practice, twice the quantity passes through the fuel which chemistry tells us is needed for combustion. Could we isolate each piece of fuel in such a manner that the whole of its surface would be surrounded by the incoming air through the grate, we might be able to come nearer the law of chemical affinity, but there are practical difficulties in the way of this; nevertheless, there is room for improvement over what might be called the rule of thumb practice universally in use.

The question resolves itself into this: *How*, *where*, and *when*, shall air be admitted to the fuel to get the best possible results?

Since the advent of the steam engine hundreds of devices have been used for the more perfect combustion of fuel, and there probably never was one of them that was of general application. To burn fuel a grate is necessary, and it must possess, first: the greatest possible amount of open space per square foot for the ingress of air to the fuel; second, it must have lasting qualities; third, and not least, it shall require as little

manual labor as possible to clean and make a fresh fire as often as necessary. It is here that combustion is made to begin, by placing on the grate the kindling wood or other like matter, the carbon of which unites at a comparatively low heat with the oxygen of the air, and creates sufficient heat to cause the carbon of the coal to unite, also, with the oxygen of the air. The ability to pass air through the fire depends on the temperature and height of the column of air in the chimney; but from the time that the coal begins to burn, leaving its ash on the grate, the passage of the air through the fuel is being obstructed, until, finally, a sufficient quantity cannot enter to the coal or carbon to convert it into heat fast enough, when the removal of the obstruction (the ash) becomes an imperative necessity. But, is not this the place to admit and control the air, according to requirement? It is here that the new condition of the fuel begins. What other place seems so propitious to admit at will an equivalent of oxygen to its affinitive (carbon) as here? But to control the supply it is evident that some other means than the chimney must be resorted to. Its power to draw air through the grate depends on the intensity of the heat which can be created or made to pass into it.

Aside from the expense consequent upon such an operation, were it practicable to do so at pleasure, there are other considerations over which there is no control. Barometric changes of the atmosphere are often of sufficient account to baffle the best efforts to

maintain even the ordinary conditions of the burning fuel. To supply air at will, mechanical means must evidently be resorted to.

So far as I am aware, no systematic attempt has ever been made to use compressed air under the steam boiler, except for the purpose of burning low-class fuels. Where employed for this purpose, its use is accompanied by an extra amount of heat, when heat is not wanted or desirable, and to the attendant dirt and discomfort. In a successful application of compressed air through the fuel, the chimney would become merely a means to convey away the spent products of combustion. Whatever the mechanical means adopted, they should be under perfect control as to quantity of air to be furnished.

Personal experience has taught me that an evenly thick fire all over the grate produces the best results. Whether there shall be much or little fuel on the grate at a time, or, in other words, a thick or a thin fire, depends on circumstances. If there is to be a short, sharp draught of steam required of the boiler, then a sufficient quantity of fuel should be placed on the grate, if possible, to last during the requirement, and should be placed there previous to the demand, and held in readiness. But if the demand be a continuous one, nearly or quite up to the boiler's capacity, then the thickness of the fire must be regulated according to the size of the coal used, whether it is hard or comparatively soft, and the strength of the draught of the chimney, and its ability for furnishing air to the fuel.

The less often the furnace doors are opened the more regular will be the supply of steam. If the fire is replenished with fuel oftener than can be avoided, not only does the fresh fuel lower the temperature in the furnace, but the ingoing air through the open doors passes rapidly along and into the flues, lowering the temperature still further as it goes.

Theoretical firing says, a small quantity of fuel at a time; *practice* says, as large a quantity as kind and size of fuel and draught of chimney will admit.

A small quantity of fuel makes a small quantity of heat, and, per contra, a greater quantity of fuel will make a larger quantity of heat. When a boiler has to supply a quantity of steam which is much less than its capability, then theoretical firing becomes practical. Under such conditions it is possible to supply a small quantity of fuel, applied at the right time, and to maintain a given pressure of steam without moving the damper, for hours. Less fuel will be consumed than if it were supplied in a quantity necessitating the whole opening of the damper to get the larger quantity of fuel in a brisk state of combustion as soon as possible, thereby preventing a lowering of the steam pressure, caused by the larger quantity of fuel cooling off the furnace on its introduction more than the small quantity did. The increased quantity of air, much in excess of chemical requirement for perfect combustion, carries with it much of the heat previously existing and remaining in the flues when light firing is being done.

To admit air above the fuel at ordinary tempera tures, and in excess of absolute requirements, is, then, the opposite of what is desirable.

Admission of air without regulation must fail in general adaptation. Success may, to a certain extent, follow in some cases; but, as a general principle, adding to the supply of atmospheric air above or beyond the fire, without some definite knowledge of absolute requirement, is just as likely to defeat the object as to assist it.

The ability to regulate implies a knowledge of the condition of the escaping gases from the burning fuel. Beyond the bridge wall little can be known as to the condition of the gases. If an instrument were devised to show the quality of gases passing underneath the boiler, we should then have some definite knowledge on the subject. Of the fuel on the grate, a practised eye can tell whether it is getting a sufficient supply of air. We have the authority of Mr. John Bourne for the statement: "In all trials it has been proven that the best results have been always attained when all the air has passed through the fire bars." Under the fire bars, then, seems to be the place to admit and regulate the supply of air to the fuel.

If the supply be heated previous to its admission, every degree it is so heated is one degree saved from the fuel in heating it to the combustion point of oxygen with the carbon of the fuel. As to what extent it may be heated, before it would have a destructive effect on the grate, experiment must determine, since

it would not be desirable to increase expenses for repairs. Whatever is done to promote combustion will be a net gain.

Where large or long boilers are in use, rapid combustion is unnecessary; but when short and compact forms are adopted (as, for instance, any of the various forms of tubulars now in use and coming into use), rapid combustion becomes a necessity. To create this, a swift supply of air through the fuel must be provided. The present mode of doing this, is by *sucking* this supply through the fuel, the power of doing it being dependent on the lightness of the column of gases in the chimney. The ability to stimulate the draft depends on the rate of combustion in the furnace. This is never fully controllable, without independent means of quickening combustion when most needed. At no time is quickened combustion more needed than after putting on a new supply of coal, when the energy languishes from the very cause which rendered a stimulus desirable.

This lack of sufficiently rapid or stimulated combustion is particularly noticeable and exceedingly undesirable when boilers are worked quite up to or near their capacity. After a fresh addition of fuel on a grate that already contains so large a quantity of ash as to materially affect the passage of air through it, cleaning the grate to facilitate the free passage of air is impracticable. Practical observation points very strongly towards some means of forcing air through the obstruction, thereby promoting combustion until a feasible time arrives for making fresh fires.

Writers on combustion are a unit in regard to the ouble quantity of air, which, it is believed, actually passes through a fuel, resulting only in imperfect combustion after all. Accepting their statements as a fact, does it seem strange that most of those who attempt to improve combustion by special devices, begin, if they do not end, by admitting more air, the additional quantity admitted remaining unknown? It is quite possible that, instead of having admitted through the grate a quantity double the amount required to convert all the carboniferous part of the fuel into carbonic acid gas, quadruple the quantity passes through the flues. The excess of oxygen can have no other effect than to absorb heat, pass into the chimney, and escape into the air. As to the nitrogen which entered with it, its neutrality is open to doubt, since it enters into a place where one of the conditions needed to effect a chemical change is present, viz., heat. Nitrogen is a diluter of oxygen, and, possibly, is capable of extracting and taking with it a certain amount of caloric.

The writer had some experience with a device for more perfect combustion, which did not require an additional supply of air. It consisted of an arch of firebrick, built over the grate. One end of the arch was joined to what would have been the bridge wall, the other end resting against the front. Through the arch were a number of orifices, through which the carbonic acid gas escaped underneath the boiler. By this arrangement the whole of the carboniferous portion of the fuel was supposed to be converted into the afore-

said gas within the oven-like arrangement. The heat that could be generated within was intense, being almost a white heat. No experiment was ever tried to ascertain whether there was a gain or not. The plan had its drawbacks, and may have had its advantages, as a promoter of combustion. Until the arch was heated to almost a white heat, there was little effect on the boiler, and it required considerable fuel and time to bring it to that state from starting a fire. Every time fresh fuel was placed on the grate, aided by the flow of air through it, the temperature would be considerably lowered, forming a very good exponent of what takes place in the flues of a steam boiler every time the fires are replenished with fuel.

However complete any arrangement may be for the attainment of perfect combustion, unless judicious means are employed for applying the heat, the best efforts may be made nugatory. The proper setting of a boiler is as important as the boiler itself. Co-operation between owners and builders of steam boilers would do much towards attaining the best possible results, as there is little reliable information of every-day practice and results in regard to the steam boiler and its fuel. There is one point that should not be forgotten by those who attempt to improve combustion by means of any system, and that is, the fireman possesses more control over the action of the fire than any additional apparatus that was ever devised.

CHAPTER IV.

THE QUALITY OF STEAM.*

EXPERIENCE shows that steam always carries a certain percentage of water in suspension as it rises from the body of water of which it is formed. This percentage will vary as between different forms of boiler, and the same boiler operated under different conditions. The water so suspended in the steam is known as water entrained or as primage. The rising of the water in a boiler by induction, when a large steam pipe is suddenly opened, is entirely independent of the water entrained, and is not meant by any allusion to primage in this chapter. I believe it is a fact observed in chemistry that anhydrous gases cannot be obtained by direct vaporization, and that a special drying process is necessary to saturate or remove the liquid always entrained in the gas upon its first formation. Saturated steam (that is, steam charged with such an amount of heat that any reduction thereof would produce condensation, and any increase thereof would produce superheat) is substantially a perfect gas, and is usually so considered in all formulæ upon its action in a steam engine.

Our best information upon the temperature (heat)

*Hill.

of saturated steam at various pressures is from the experiments of Regnault, *Comptes Rendus*, 1847, with which all steam engineers are sufficiently familiar to avoid the description of his apparatus or the circumstances under which his experiments were made, at this time. It is proper to state, however, that the experiments of Regnault were to ascertain the relations of temperature, pressure, and density of steam; and as a corollary to determine the specific heat of steam and water at various boiling points. The determination of the relation of density and pressure was never made by Regnault, the only recorded experiments upon which were by Messrs. Fairbairn and Tate, several years later.

It is now well kown that the steam engine is a heat engine, that the water which is vaporized to form steam is simply a vehicle in which we store up the heat of the fuel, and which parts with a portion of this heat in transit through the engine, partly by conversion of heat into work, partly by conduction and radiation through the walls of the cylinder, and partly by the cooling effect of the atmosphere on the piston rod. No steam is expended in operating an engine; for the same weight of water as vapor which enters the cylinder by the steam pipe also leaves the cylinder by the exhaust pipe. If we deliver 1,000 pounds of steam at a given temperature to an engine through the steam ports, we shall draw off through the exhaust ports precisely the same weight of steam at a lower temperature. But during the passage of this steam through

the engine a certain reduction of temperature has occurred, and the efficiency of the engine is a function of the limits of temperature between which the steam enters and leaves the cylinder, as enunciated by the junior Carnot more than fifty years ago.

To illustrate the efficiency upon the heat basis, let us suppose an engine condensing—consuming—16½ pounds of steam per hour, connected with a battery of boilers furnishing 10 pounds of steam per pound of coal from the temperature of the feed. Let the thermal value of the coal be taken at 15,000 units, and estimate 75 per cent. of this, or 11,250 units, as contained in the steam above the temperature of feed water. Then the efficiency of such an engine would be

$$100 \times \frac{11{,}250 \times 1{\cdot}65 \times 772}{33{,}000 \times 60} = 13{\cdot}82$$

per cent., or of every 100 horse-power resident in the heat expended in working the engine, less than 14 are utilized, the remaining 86 horse-power going out in the exhaust. It is well known that the best economy we have any record of has been obtained from pumping engines, and that a duty of 100,000,000 foot-pounds per 100 pounds of coal is seldom attained. Now, our condensing engine, working upon 16½ pounds of steam, or one and sixty-five hundredths pounds of coal per hour, represents a duty of

$$\frac{33{,}000 \times 60 \times 100}{1{\cdot}65} = 119{,}988{,}000,$$

nearly 120,000,000 foot-pounds. From which it ap-

pears that about 14 per cent. is about a maximum efficiency with our present knowledge of construction. The object of this chapter is, however, not to discuss the economy of steam machinery, but to show the necessity for an exact knowledge of the thermal value of steam, in estimating the economy of engine and boiler performance.

To illustrate the effect of a lack of knowledge of the quality of steam furnished by boilers, let us suppose a temperature of feed of 212° Fahr., an expenditure of coal of 1,000 pounds, a consumption of feed-water of 12,000 pounds, and a boiler pressure by gauge of 125 pounds. The apparent evaporation from the temperature of feed in this instance is twelve pounds of steam to one of coal. Without information to the contrary, and in accordance with the usual practice, we would accept this as the evaporation, and pronounce the result as extremely satisfactory. Suppose, however, the temperature of the steam, instead of being at saturation (1,221.53 units), contained as a mean per pound only 1,135 units; then the actual evaporation, instead of being twelve to one, would be ten and eight-tenths to one, and this instance supposes an efficiency of furnace and boiler of nearly 75 per cent., and a thermal value of 15,000 units per pound of coal; in brief, supposes a quantity of coal and efficiency of furnace rarely obtained. None of the usual devices appli d to steam boilers are capable of measuring the thermal value of steam, and recourse is had to special apparatus for this purpose. Two distinct forms of calorimeter have been

used; one the continuous calorimeter, in which the condensation of a certain small percentage of the steam is maintained during the entire trial of a steam engine or boiler, and the other the intermittent calorimeter, with which at stated intervals known weights of steam are drawn from the boiler or steam pipe and condensed in known weights of water.

The continuous calorimeter consists usually of a coil of brass pipe or copper of ¼ to ½ inch diameter of bore, containing 30 to 50 lineal feet. This coil is placed within a tin can, through which the circulating water passes from below upward. The upper end of the worm is connected with the steam pipe or steam drum of the boiler, and the lower end terminates in a neck which delivers the condensed steam into a receptacle mounted upon a carefully-balanced scale, with which the condensation is weighed from time to time, and dumped. The circulating or condensing water is measured by tanks of known capacity, or through a Worthington meter, the error of which is known by test. Standing thermometers are located as follows: One in the injection pipe, by which the circulating water enters the apparatus; one in the overflow nozzle, by which the circulating water leaves the apparatus; and one in the neck of the worm from which the water of condensation flows. Should there be an indication from the calorimeter data of superheat in the steam, an additional thermometer should be inserted in the head of the worm or in the steam pipe leading to it, to measure the superheat independently and

check the record of the calorimeter. Steam flows through the worm and is condensed, the heat being transferred through the walls of the coil to the circulating water. The temperature of the circulating water is elevated through a range represented by the difference of temperature of the inflow and outflow. The temperature of the condensation as it leaves the calorimeter is read from the thermometer in the neck of the worm. The temperature of the steam is the unknown quantity which we seek. To illustrate the action of the continuous calorimeter, assume a weight of steam condensed of 100 pounds, a weight of circulating water expended in condensing it of 2,000 pounds, a temperature of inflow of 50° Fahr.; a temperature of outflow of 105° Fahr., and a temperature of condensation of 60°; then the temperature of steam, neglecting small effect of variation in the specific heat, is

$$60 + \frac{2{,}000 \times 55}{100} = 1{,}160° \text{ F.}$$

Assume the steam as it entered the calorimeter, at a pressure of 135 pounds by gauge or 150 pounds absolute, at which pressure the temperature of saturation is, according to Regnault, 1,223·15 Fahr. Then difference of temperature is 63.18 units, indicating that a portion of the water was entrained in the steam.

To estimate the percentage of primage we must bear in mind that the water in the boiler is first heated to a temperature of 362·56° Fahr. (corresponding to a pressure by gauge of 135 pounds), before vaporization takes

place; and that additional temperature of 860·2 units is necessary to vaporize the water so heated; and that the discrepancy in the thermal value of the steam applies to the temperature of vaporization, whence the water entrained as primage becomes

$$100 \times \frac{63{\cdot}18}{860{\cdot}2} = 7{\cdot}35 \text{ per cent.}$$

The intermittent calorimeter consists of a water-tight vessel (preferably of wood, to avoid transfer of heat to or from the contents thereof by conduction and radiation) mounted upon a sensitive scale, into which a known weight of water is drawn. A small steam pipe, usually three-quarters of an inch in diameter, closely connected with the main steam pipe or steam drum of the boiler, dips into the vessel on the scale, and is provided with a cock or open-way valve to regulate the delivery of steam into the weighed quantity of water. The temperatures are taken with a hand thermometer. As suggested, a known weight of water is first weighed into the tank on the scale, usually some convenient quantity to estimate from, as 100 or 200 pounds, of which the probable condensation in the small steam pipe usually forms a part. The amount of condensation which will collect in the steam pipe between observations will vary with the quality of steam, and must be blown out to clear the pipe before the weighed quantity of steam to be condensed is blown in. The weight of water and condensation blown out of the pipe having been justified, the temperature of

the contents of the tank is carefully taken with a reliable thermometer, and 5 or 10 pounds of steam blown in and condensed. (The weight of steam condensed should be as large as consistent with a limited temperature of the contents of the tank on the scale, to obtain a high range of temperature; since errors of weight are less liable to occur than errors of temperature, and the greater the range of the mercury the smaller the effect of errors of observation.) The desired weight of steam having been condensed, the flow through the pipe is promptly suppressed and a second temperature of the contents of the tank is taken. The first temperature from the second temperature represents the range of the contents of the tank. To illustrate the principle of the intermittent calorimeter, let the following data be assumed:

Weight of condensing water	100 pounds.
Weight of steam condensed	5 "
Initial temperature condensing water . . .	60 F.
Final temperature condensing water . . .	115 F.
Range	55 F.

and the temperature of steam is

$$115 + \frac{100 \times 55}{5} = 1{,}228 \text{ F.}$$

Supposing steam, as before, at a pressure absolute of 150 pounds, the difference between the quality in the illustration and saturated steam is 4·82 units, corresponding to a superheat of

$$\frac{4{\cdot}82}{0{\cdot}475} = 10{\cdot}15 \text{ F.}$$

We shall refer only to a few experiments to show the value of investigations of this class. The first results we will examine are from a series of four experiments upon boilers set with smoke-preventing furnaces for the Cincinnati Industrial Exposition for 1879.

The first case was a return tubular containing 963.64 superficial feet of heating surface, and worked at a capacity equivalent to 2.77 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 960.46 units, indicating, with a pressure by gauge of 38.75 pounds, a primage of 26.26 per cent. The apparent evaporation from the temperature of feed (70.02° F.) per pound of coal was 7.59 but the actual evaporation from same temperature was only 5.6 to one.

The second case was a return flue boiler containing 519.45 superficial feet of heating surface, and worked at a capacity equivalent to 1.73 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 864.73 units, indicating with a pressure by gauge of 80.29 pounds, a primage of 29.13 per cent. The apparent evaporation per pound of coal from the temperature of feed (166.01 F.) was 5.84, but the actual evaporation from same temperature was 4.14 to one.

The third case was a battery of 2 return tubular boilers containing 880.16 superficial feet of heating surface, and worked at a capacity equivalent to 3.20 pounds of steam per foot of heating surface per hour,

which gave a temperature of steam of 1,005.93 units, indicating with a pressure by gauge of 76.18 pounds, a primage of 23.19 per cent. The apparent evaporation per pound of coal from the temperature of feed (169.11° Fahr.) was 9.69, but the actual evaporation was 7.45 to one.

The fourth case was a direct tubular boiler containing 327.79 superficial feet of heating surface, and worked at a capacity equivalent to 2.96 pounds of steam per foot of heating surface per hour, which gave a temperature of steam of 1,441.35 units, indicating, with a pressure by gauge of 81.60 pounds, a superheat of 18.83 per cent. The apparent evaporation per pound of coal from the temperature of feed (74.55° Fahr.) was 8.80, but the actual evaporation upon the basis of saturated steam was 10.66 to one. This boiler was set and worked simply for test purposes, and was furnished with superheating surface. The continuous calorimeter was used in these experiments. The next results to which I shall refer are the calorimeter tests for quality of steam during the trials of steam engines at the Millers' Exhibition, Cincinnatti, 1880. In this instance the experiments were all made with the same boilers, operated under approximately the same conditions from day to day. The boilers, two return tubular, contained 137.24 superficial feet of heating surface, and were worked at the following capacities in pounds of steam per foot of heating surface per hour, for six different trials: 2.53, 2.42, 2.32, 2.41, 2.42, and 2.63—with corresponding temperature of

steam of 1,243.84 units, 1,211.3 units, 1,315.86 units, 1.255.74 units, 1,301.65 units, and 1,313.11 units. Of these temperatures only one, the second, indicates primage; all others exhibit a slight superheat. The primage at 92.54 pounds pressure by gauge in the second experiment was 0.46 per cent. The percentage of superheat at 92.50 pounds pressure by gauge in the first experiment was 2.3; in the third experiment, with steam pressure at 91.65 pounds by gauge, 8.3 per cent.; in the fourth experiment, with steam pressure at 91.48 pounds by gauge, 3.34 per cent.; in the fifth experiment, with steam pressure at 91.44 pounds by gauge, 7.09 per cent., and in the sixth experiment, with steam pressure at 91.54 pounds by gauge, 8.06 per cent. The continuous calorimeter was used in these trials.

The former results were from four different boilers of different forms and dimensions, and operated at different steam pressures and rates of evaporation, with a range in the quality of steam from 19 per cent. of superheat to 29 per cent. of primage; while the last six results were all from the same boilers, operated at different times, under approximately the same steam pressure and rates of evaporation, with a range in the quality of steam from 8.3 per cent. of superheat to ½ per cent. of primage. From which it appears that with the same boiler or boilers, operating under similar conditions, an approximately uniform quality of steam should be had, and that the quality of steam in any one instance cannot be assured for another, unless the conditions are precisely alike.

The next results to which I shall refer are from three different trials upon the same boilers, operated with similar steam pressures, and at different rates of evaporation. The boilers, two in the battery, were of the return tubular variety, containing 932.02 superficial feet of heating surface. During the first trial. steam was made at the rate of 4.09 pounds per foot of heating surface per hour, with a resultant temperature of 1,153.09 units, indicating a primage at 92.59 pounds by gauge of 7.08 per cent.

During the second trial the boilers were worked at an evaporation equivalent to 2.86 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,199.04 units, indicating, with a pressure of 92.95 pounds by gauge, a primage of 1.92 per cent.

During the third trial the boilers were worked at a rate of evaporation equivalent to 2.90 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,174.17 units, indicating, at a gauge pressure of 92.28 pounds, a primage of 4.75 per cent. These experiments were made with an intermittent calorimeter. In all experiments exhibiting a small primage in the steam, as a superheat, the boilers were set to expose more or less of the steam room to contact with the hot gas.

The next results are from a series of three experiments with a small locomotive boiler, operated standing.

For the first trial the heating surface was 288.75 superficial feet, and ratio of heating to grate surface

25.90 to one. The boiler was worked at a capacity equivalent to 8.49 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,150.98 units, indicating at 105.5 pounds pressure, by gauge, a primage of 5 per cent. The apparent evaporation per pound of coal was 4.45, and the actual evaporation was 4.09 to one.

For the second and third trials the heating surface, by the introduction of a water bridge into the fire box, was increased to 300.7 superficial feet, with a ratio of heating to grate surface of 41.67 to 1. During the second trial the boiler was worked at a rate of evaporation equivalent to 9.39 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,181.76 units, indicating at 98.25 pounds pressure, by gauge, a primage of 4.33 per cent. The apparent evaporation in this case was 7.58 pounds, and the actual evaporation 7.25 pounds of steam to 1 of coal.

During the third trial the boiler was worked at a rate of evaporation equivalent to 9.77 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,259.29 units, indicating a superheat of 88.67° F., at a pressure, by gauge, of 100.7 pounds. The apparent evaporation was 6.41 pounds of steam per pound of coal, and the actual evaporation upon the basis of saturated steam was 6.65 to 1. The rate of combustion and evaporation was higher for the third trial than for the second, with a better quality of steam and a reduced economy. In these trials the coal was burned within five or six per cent. of the total weights

charged, and the calorimeter results can be fairly compared without correction.

The next result to which I will refer is from the boiler of a "Rogers" engine on the Ohio and Mississippi Railroad, in a running trial from Vincennes to Seymour, made last July. The heating surface was 984.33 superficial feet, and the rate of evaporation equivalent to 9.51 pounds of steam per foot of heating surface per hour, with a temperature of steam of 1,192.11 units, indicating a primage of 3.4 per cent., at a pressure, by gauge, of 125.56 pounds. The apparent evaporation in this instance was 3.97 pounds per pound of coal, and the actual evaporation was 3.83 to 1. The poor economy of this boiler was largely due to the high rate of coal consumption (146.25 pounds per superficial foot of grate per hour). With large grate areas and a reduced rate of combustion per superficial foot of grate per hour, the economy of locomotive boilers may be materially improved, as shown by the results obtained with the "Wooten" boiler on the Philadelphia and Reading Railroad.

I am aware that some of my professional friends are not seized of my faith in the reliability of calorimeter results, but I am unable to obtain from them any better objection than that some modifying data have been overlooked or neglected in those cases which do not meet their approbation. However, when they agree, as they invariably do, that condensed steam and condensing water may be accurately weighed, and that approximately accurate temperatures may be had with

good makes of thermometers, then I can conceive no other objections to accepting the results of calorimeter experiments than the personal errors of observation which pervade all mechanical investigations.

If the power of steam engines is to be measured by the indicator, or the less reliable dynamometer or friction brake; if the economy of boilers and engines is dependent upon the accuracy of weighing scales; if steam pressures are to be taken from spring gauges, and temperatures read from mercurial thermometers, and such results are held to be reliable for absolute and comparative effect; then the same reliability must, in simple justice, be accredited the calorimeter, for it depends solely upon correct weights and temperatures, and involves no complex or uncertain quantities in the operation.

CHAPTER V.

THE MECHANICAL POWERS—VIRTUAL VELOCITIES.*

YEARS ago, when I knew much less than I think I do now, I would have been saved many a wild-goose chase after mechanical impossibilities and perpetual motions, had I been well grounded on the theory of *virtual velocities*—I think they call it now, or as we then knew it, "whatever is gained in time is lost in power," and *vice versa*. There may be a few of my younger readers who would be benefited by a practical and simple illustration of the same. Several of them are probably champions of some special device for directing or utilizing an original force. I used to hear hotly contested arguments in favor of the "screw power," or "hydraulic press power" as the "boss" of them all. Such of my readers as have formed similar preferences for different "powers," no doubt believe in the practicability of perpetual motion, etc. For them this chapter is intended, as they have something to learn. It will first be necessary for them to learn that no combination of mechanical devices increases or returns more force or power than is originally applied to it. That, owing to friction, etc., it actually returns less. That it all figures down to a small force acting through a great space, or a great force acting through a small

* Hook.

space. The force exerted by a single man might be made to move a weight equal to all the buildings in New York city—strength of material and time permitting. The screw, hydraulic press, etc., are merely devices which require that a small propelling force move through a comparatively great distance to effect the small movement of a heavy weight. The lever illustrates the action of all mechanical devices to apply power. The device, whatever it may be, is merely the *harness* that makes the strength of the horse available in drawing the wagon; but in no way increases the horse's strength. Thus in Fig. 1 we have a lever, the long end being ten feet, to which is attached a ten pound weight. The short end is one foot and supports a 100 pound weight. It is plain that—not taking into consideration the weight of the lever itself—the weights exactly balance each other. If we wish to raise the 100 pounds one foot, it is plain the ten pounds must move through *ten* feet to accomplish it, as the long end is ten times longer than the short end. From this we can deduce a very useful rule of universal application, as follows: The propelling force, multiplied by the distance through which it moves, equals the resistance or weight, multiplied by the distance through which it moves to balance the former. The practical application of this may be seen in the lever again. Thus we wish to raise 200 pounds through one foot with the force of ten pounds. To do this it is plain that the 10 pounds must move through a greater distance than it did to raise the 100 pounds, and to do this its end

of the lever must be greater. But how much greater? —that's the question. Let us apply the rule, which states that the resistance × by its movement must equal the force × by its distance. The 200 pounds are to be raised one foot, therefore $200 \times 1 = 200$. Now the product 200 equals the product of the propelling force 10 multiplied by the distance it moves through (or the length of the lever in this case). We know one factor of the propelling force, viz.: 10 pounds, and to obtain the other we have only to divide the product 200 by the 10 pounds to get 20 feet, the length of the lever necessary. It is necessary to understand the lever perfectly, and to do this it must be remembered that, in any of the different forms of the lever, the force and resistance to equalize each other must, when multiplied by their ends of the lever, equal each other—that is, the products must; and having any three of the factors we may find the fourth by dividing the couple by the third. What is true of the lever is true of all other devices; it is a mere question of force acting through space. A very useful application of the above principles is in finding the weight that can be raised by a block and tackle.

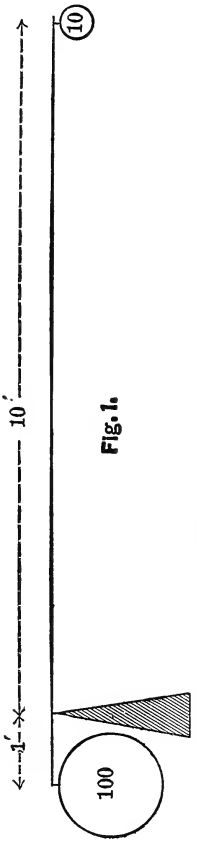


Fig. 1.

Notice how many feet a point on the end of the rope you pull on moves through, to raise the hook to which the load is attached *one* foot. Suppose the point moves through eight feet while the hook moves one, the leverage is 8 to 1, and it is plain that if you exert 100 pounds with your hands you will raise a load of $8 \times 100 = 800$; but your hands pull the rope through *eight* feet, and your load (which is eight times the power) moves through but *one* foot. The combination of the screw and lever comes under this rule. Thus notice how many inches the end of the lever, to which the power is attached, moves through to advance the screw *one* inch. Suppose it moves through 100 inches, the leverage is 100 to 1, and if you pull 100 pounds on the lever you will lift $100 \times 100 = 10{,}000$ pounds, *but only through one inch, while your power travels through 100 inches.*

The wedge's force may be ascertained, by dividing the distance it travels into the log being split, by the distance the crack or split opens; the quotient is the leverage or advantage, which multiplied by the force of the blow, equals the rending or splitting force. Again, the pressure on an engine's piston $\times$, by the space it moves through in a given time, is the power it exerts, theoretically. If we wish to double the force of an engine, we double the number of feet the piston travels in a given time, or we may double the steam pressure; thus increasing the force, or the distance traveled in a given time, increases the effect proportionally.

This leads me to another application to which these principles can be applied. In designing, for instance, the crank of an engine, suppose the pressure on the piston is 20,000; this is transmitted by the rod, etc., to the pin A. (Fig .2.) This strain on the pin has a ten-

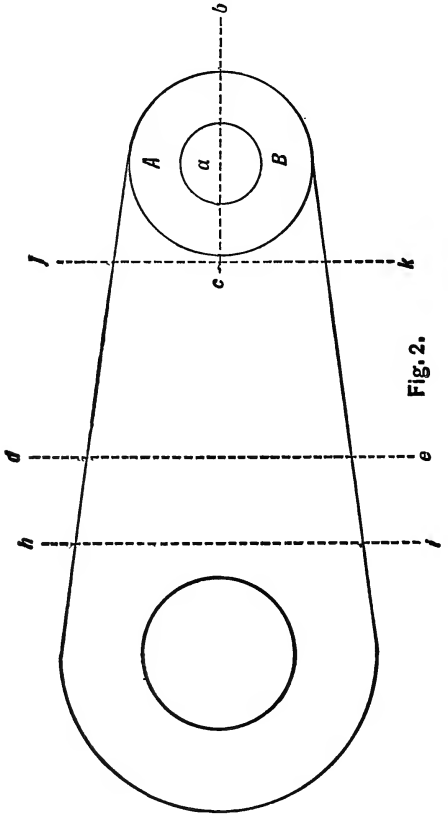


Fig. 2.

dency to fracture the pin put through the line *c b*; that is, lift or tear the part A from the part B. The safe tensile load for cast iron is about 2,000 pounds per square inch of section; hence to have the hub large enough, it must present an area of solid metal of 20,000÷2,000 = 10 square inches. The portion or section of the crank, *j k*, may be ascertained by considering the crank a beam, fixed at one end and loaded at the other. The section *d e* must be twice as strong as *j k*, as it moves through but half the distance that *j k* does, and the section *h i*, moving but one-third the distance, must have an area of three times that of *j k*. Thus, in designing any machine, after ascertaining the motion and strain on the leading part, we may proportion the balance from it

CHAPTER VI.

THE FIRST RAILROADS IN AMERICA.

THE first railroad built in the United States was three (3) miles in length, extending from the granite quarries of Quincy, Massachusetts, to the Neponset river. This road was begun in 1826, and completed the next year. It was built on granite sleepers, seven and one-half (7½) feet long, laid eight (8) feet apart. The rails were laid five (5) feet apart, were made of pine wood a foot deep, covered with oak, and these with flat iron bars. This road was used to transport granite stone from the quarries to the river.

The second railroad was begun and finished in 1827. It extended from the coal mines of Mauch Chunk, Pennsylvania, to the Lehigh river, a distance of nine (9) miles. The rails were made of wood, laid on wooden sleepers, and were covered with flat iron bars. The loaded cars descended by gravity (the road being on an incline), and were drawn back empty by mules.

In 1828 the Delaware and Hudson Canal Company constructed a railroad from their coal mines to Honesdale, the termination of their canal. These (3) railroads were used wholly to move the products of the mines of their respective owners. The Baltimore & Ohio Railroad and the South Carolina Railroad were begun

in 1828, and were the first railroads intended for public use. Others soon followed in different parts of the country: notably, the New Castle & Frenchtown Railroad, connecting the Chesapeake and Delaware bays, which for many years was the connecting link and great thoroughfare for passenger travel between the North and South. This railroad, which was finished in 1831, was sixteen (16) miles long, and at that time the best-laid road in the country.

CHAPTER VII.

THE FIRST LOCOMOTIVE IN AMERICA.

THE first locomotive ever run on a railroad in America was undoubtedly the "Stourbridge Lion," Fig 3, one of three engines built at Stourbridge, in England, and imported into this country by that eminent American engineer, Horatio Allen, Esq., of New York, for use on the Delaware and Hudson Railroad, previously mentioned. Of the three locomotives imported for this company the "Stourbridge Lion" was the only one put to work. It was a first-class engine for that time, and worked very well, and would have done excellent service had the trestle work, upon which most of the road was built, been strong enough to stand the weight of the engine when at work. This it was too weak to do, and the engine was taken off the road and laid aside

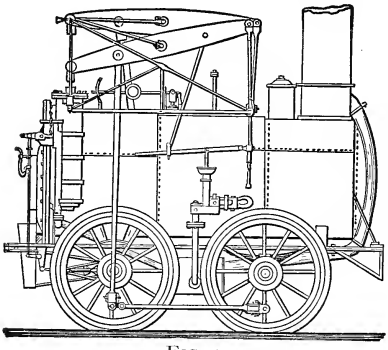


FIG. 3.

Mr. Allen in describing its first trip on the road

says he was the only person on the engine at the time, and he was, therefore, the first engineer who ever ran a locomotive in America. The "Lion" had vertical cylinders, with four driving wheels all connected. The boiler was very like the locomotive boiler of the present day, in having a fire-box, with five flues leading to the smoke-box—it was, in fact, the first step towards the present multitubular boiler. In 1832 other English engines were imported for use on the New Castle & Frenchtown Railroad and other roads, and put to work, and gave great satisfaction. They were of the most improved English type, and were greatly superior in design and workmanship to any that had then been seen in this country. When they arrived at New Castle, Delaware, it became necessary to select a skilled mechanic to put them together as soon as possible. This task was assigned to Matthias W. Baldwin. In putting these engines together, Mr. Baldwin had all the advantages of handling their parts and studying their proportions, and in making drawings therefrom. This proved of great service to him when he received an order in 1832 to build a locomotive for the Philadelphia & Germantown Railroad.

CHAPTER VIII.

FIRST AMERICAN LOCOMOTIVE.

FIGURE 4 shows a sketch of the first locomotive built in America. It was built by the venerable Peter Cooper, of New York city—a name well-known and deservedly respected throughout the entire length and breadth of this country. The following is a letter written by him to Mr. Brown, the author of "The History of the First Locomotive in America." The letter was written to explain the cause which led the writer to deviate from the path of his legitimate business to become the builder of a locomotive. Our cut, for which we are indebted to the *Railroad Gazette*, of New York, represents the locomotive below referred to:

"NEW YORK, MAY 18, 1869.

"MY DEAR SIR: In reply to your kind favor of the 10th inst., I write to say that I am not sure that I have a drawing or sketch of the little locomotive placed by me on the Baltimore and Ohio Railroad in the summer of 1829, to the best of my recollection.

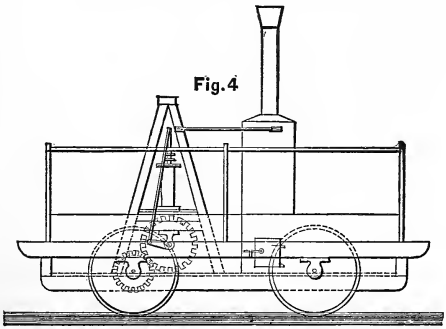
"The engine was a very small and insignificant affair. It was made at the time when I had become the owner of all the land now belonging to the Canton Company, the value of which, I believe, depended almost entirely upon the success of the Baltimore and Ohio Railroad.

"At that time an opinion had become prevalent that the road was ruined for steam locomotives, by reason of the short curves found necessary to get around the various points of rocks found in their course. Under these discouraging circumstances, many of the principal stockholders were about abandoning the work, and were only prevented from forfeiting their stock by my persuading them that a locomotive could be so made as to pass successfully around the short curves then found in the road, which only extended thirteen miles, to Ellicott's Mills.

"When I had completed the engine, I invited the directors to witness an experiment. Some thirty-six persons entered one of the passenger cars, and four rode on the locomotive, which carried its own fuel and water; and made the first passage, of thirteen miles, over an average ascending grade of eighteen feet to the mile, in one hour and twelve minutes. We made the return trip in fifty-seven minutes.

PETER COOPER'S LOCOMOTIVE.

Fig. 4



THE FIRST ONE BUILT IN AMERICA.

"I regret my inability to make such a sketch of the

engine as I would be willing to send you at this moment, without further time to do so.

"Yours, with great respect,

"PETER COOPER."

The boiler of Mr. Cooper's engine was not as large as the kitchen boiler attached to many a range in modern mansions; it was of about the same diameter but not more than half as high. It stood upright in the car, and was filled above the furnace, which occupied the lower section, with vertical tubes. The cylinder was but three and a half inches in diameter, and speed was gotten up by gearing. No natural draught could have been sufficient to keep up steam in so small a boiler; and Mr. Cooper used, therefore, a blowing-apparatus, driven by a drum attached to one of the car wheels, over which passed a cord that in its turn worked a pulley on the shaft of the blower. Among the first buildings erected at Mount Clare was a large car-house, in which railroad tracks were laid at right angles with the road track, communicating with the latter by a turn-table, a Lilliputian affair indeed compared with the revolving platforms, its successors, now in use.

In this car-shop Mr. Cooper had his engine, and here steam was first raised. With his own hands he opened the throttle, admitted the steam into the cylinder, and saw the crank-substitute operate successfully with a clacking noise, while the machine moved slowly forward with some of the bystanders who had stepped upon it. And this was the first locomotive for rail-

road purposes ever built in America; and this was the first transportation of persons by steam that had ever taken place on this side of the Atlantic on an American-built locomotive.

Mr. Cooper's success was such as to induce him to try a trip to Ellicott's Mills, on which occasion an open car, the first used upon the road, having been attached to the engine, and filled with the directors and some friends, the first journey by steam in America on an American locomotive was commenced. The trip was most interesting. The curves were passed without difficulty, at a speed of fifteen miles an hour, and the grades were ascended with comparative ease. The day was fine, the company in the highest spirits, and some excited gentlemen of the party pulled out memorandum books, and, when at the highest speed, which was eighteen miles an hour, wrote their names and some connected sentences, to prove that even at that great velocity it was possible to do so. The return trip from the Mills, a distance of thirteen miles, was made in fifty-seven minutes. This was in the summer of 1830: but the triumph of this Tom Thumb engine was not altogether without a drawback. The great stage proprietors of the day were Stockton and Stokes; and on that occasion a gallant gray, of great beauty and power, was driven by them from town, attached to another car on the second track—for the company had begun by making two tracks to the Mills —and met the engine at the Relay House on its way back. From this point it was determined to have a

race home; and the start being even, away went horse and engine, the snort of the one and the puff of the other keeping time and time.

At first the gray had the best of it, for his steam would be applied to the greatest advantage on the instant, while the engine had to wait until the rotation of the wheels set the blower to work. The horse was perhaps a quarter of a mile ahead, when the safety-valve of the engine lifted, and the thin blue vapor issuing from it showed an excess of steam. The blower whistled, the steam blew off in vapory clouds, the pace increased, the passengers shouted, the engine gained on the horse; soon it lapped—the silk was applied—the race was neck and neck, nose and nose—then the engine passed the horse, and a great hurrah hailed the victory. But it was not repeated, for just at this time, when the gray's master was about giving up, the band which drove the pulley which moved the blower slipped from the drum, the safety-valve ceased to scream, and the engine, for want of breath, began to wheeze and pant. In vain Mr. Cooper, who was his own engineer and fireman, lacerated his hands in attempting to replace the band upon the wheel; in vain he tried to urge the fire with light wood. The horse gained on the machine and passed it, and although the band was presently replaced, and steam again did its best, the horse was too far ahead to be overtaken, and came in the winner of the race. But the real victory was with Mr. Cooper, notwithstanding. He had held fast to the faith that was in him, and had demonstrated its truth beyond peradventure. All honor to his name!

The second locomotive ever built in this country, and the first for actual service on a railroad, was the "Best Friend," built by the West Point Foundry, New York., for Mr. E. L. Miller, of Charleston, S. C., for use on the South Carolina Railroad. The "Best Friend," Fig. 5, was a four-wheel engine, all four wheels being drivers. Two inclined cylinders, at an angle, working down on a double crank inside of the frame, with the wheels outside of the frame, wheels connected together on the outside by side rods. The wheels were made with iron hubs, wooden spokes and felloes, with iron tires, and iron webs and fins in the wheels to connenct the outside rods to.

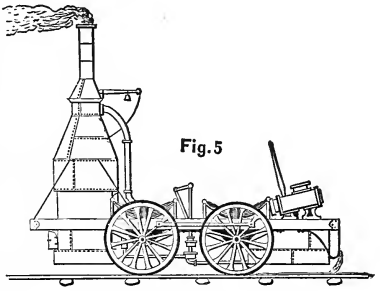


Fig.5

BEST FRIEND, 1830.

The boiler was a vertical one, shaped something like a porter bottle; the boiler set in the centre of the four wheels, with connecting rods running by it to the crank shaft. The cylinders were 6 inches in diameter by 16 inches stroke; the wheels about 4½ feet in diameter. The whole machine weighed about 4½ tons. It was sent to Charleston, S. C., in the fall of 1830, and put to work soon after.

It ran long and successfully. One day while Mr. Darrell, the engineer, was making up the train (there

being no conductors or brakemen in those days), the negro fireman put his weight on the safety valve to prevent the steam escaping, and exploded the boiler, causing his own death, with that of another negro, and the scalding of Mr. Darrell. In the "Best Friend," we had not only the first American locomotive in actual use, but also the first locomotive boiler explosion on record.

The third locomotive built in America was called the "West Point," built in 1830, by the West Point Foundry of New York, from plans by Horatio Allen, Esq., for the South Carolina Railroad, and set to work in Feb., 1832. This locomotive had the same size of engine frame, wheels, cranks, etc., as the "Best Friend," but had a horizontal tubular boiler. The tubes were 2½ inches in diame er, and six feet long

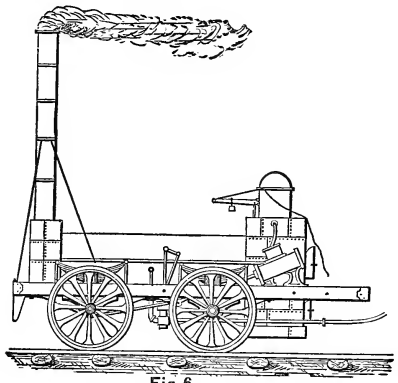


Fig. 6

WEST POINT, 1830.

The working of this engine in actual service was very satisfactory. Mr. Nicholas W. Darrell was appointed engineer, and ran it from the time it was put on the road. As he had charge of the "Best Friend" also, he was the first American locomotive engineer;

Mr. Allen and Mr. Cooper having run engines only on experimental trips.

The fourth American-built locomotive was the "De Witt Clinton," built also by the West Point Foundry,

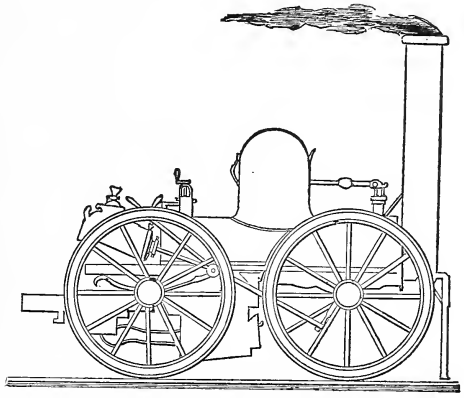


FIG. 7. DE WITT CLINTON, 1831.

for the Mohawk and Hudson River Railroad, New York, in 1831, shortly after the "Best Friend" and "West Point" were completed and shipped to Charleston. This engine had two cylinders 5½ inches in diameter, and 16 inches stroke; four wheels, all drivers, which were 4 feet 6 inches in diameter. The hubs were made of cast iron, spokes of wrought iron, with inside cranks and outside connecting rods to connect all four wheels. The boiler was a tubular one, with a drop furnace, two fire-doors, one above the other, copper tubes 2½ inches in diameter, and six (6) feet long. The cylinders were inclined, and the pumps were worked by bell cranks. This engine weighed

about 4 tons, and would run about 30 miles an hour with five cars on a level road, using *anthracite* coal. It was the first engine ever used in the State of New York; David Matthew was the engineer.

In 1832 Davis & Gartner, of York, Pa., built several locomotive engines of the "Grasshopper" type, for the Baltimore & Ohio Railroad, from designs by Phineas Davis and Ross Winans. These engines had vertical boilers, similar to those now used on steam fire-engines, 51 inches in diameter, and containing 282 fire tubes, 16 inches long, and tapering from 1½ inches at the bottom to 1¼ inches at the top, where the gases discharged through a combustion chamber into the stack. These engines weighed about 6½ tons.

One of these engines, the "Atlantic," Fig. 8, was set to work in September, 1832, and hauled 50 tons over a rough road, with high grades and short curves, at the rate of 15 miles per hour. This engine made a round trip at a cost of $16, doing the work of 42 horses, which had cost $33 per trip. The Baltimore & Ohio Railroad exhibited one of these engines at the Centennial Ex-

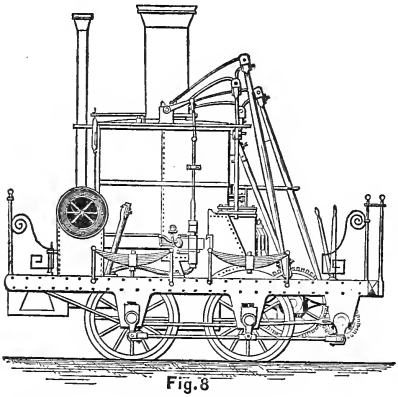
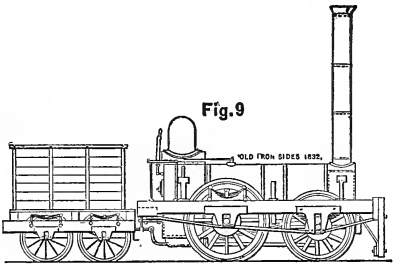


Fig. 8

ATLANTIC, 1832.

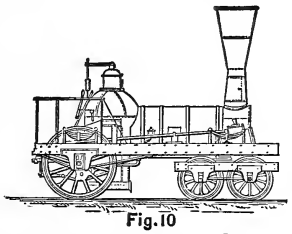
hibition, Philadelphia, in 1876, and there are one or more still used as shifting engines at Mount Clare Station, Baltimore, Maryland.

In November, 1832, M. W. Baldwin, the founder of the celebrated Baldwin Locomotive Works, built a locomotive named the "Old Ironsides," for the Camden and Amboy R. R., which did good service for 20 years. It was a close copy of the English engines used on the New Castle and Frenchtown Railroad, with a few minor improvements. It attained a speed of 28 miles per hour. It is creditable to Mr. Baldwin as an engineer, that this engine was the first and last of his imitations of the English locomotives. He, following the rest of the American builders that had entered the business, aimed too at making an American locomotive, and his second engine and those succeeding it were different in design from the "Old Ironsides."



OLD IRONSIDES, 1832.

In 1834, M. W. Baldwin built for Mr. E. L. Miller, of Charleston, S. C., a locomotive—named after that gentleman—for use on the



THE E. L. MILLER, 1834.

South Carolina Railroad. This engine was a six-wheeled engine, with cylinders 10 inches in diameter, and 16 inches stroke. He made the boiler of a form which remained standard for many years, with a high dome over the fire-box. By the end of 1834 he had built five locomotives, and by this time (1834), locomotive engine building had become one of the leading and most promising industries of the United States. William Norris, of Philadelphia; Hinckley & Drury, of Boston; Ross Winans, of Baltimore, and other builders, entered the field, each and all improving the then existing types, until we have the American locomotive of to-day—one of the most perfect pieces of mechanism wrought out by the hand and mind of man.

CHAPTER IX.

CONSTRUCTION OF LOCOMOTIVES.

A LOCOMOTIVE engine must combine within itself the means for the generation of steam, its application to produce motion within the engine itself, and also the propulsion of the whole upon the road. A complete locomotive engine, therefore, combines three distinct arrangements for realizing these conditions. The source of power lies in the boiler and fire-box; the cylinders, valve, piston, and the various connections, are the means by which it is applied to produce motion within the machine itself; and the wheels by their adhesion, or tractive force, secure the locomotion of the machinery which impels them, and also from their surplus power, above what is necessary to move the engine alone, the drawing of a great load upon the rails. It is, therefore, necessary for the student to understand the construction of each of these parts, and also the general arrangement by which they are combined for the production of power.

Fig. 11 shows, or will serve to show, the general construction of an ordinary eight-wheeled engine, divided in the direction of the length of the boiler, so as to show the entire machinery for generating and applying the power. The boiler *N*, *N*, *N*, in which

the steam is first produced, is of a cylindrical form, having a furnace or fire-box *B*, at one end, surrounded by a water casing, communicating with the boiler, and which is to prevent the destruction of the plates of which the fire-box is formed, by the intense heat of the fire. The plates which form the outside of this water-casing are united to the cylindrical part of the boiler, and form what is called the outside fire-box. This outside fire-box supports the furnace or

THE AMERICAN LOCOMOTIVE, 1883.

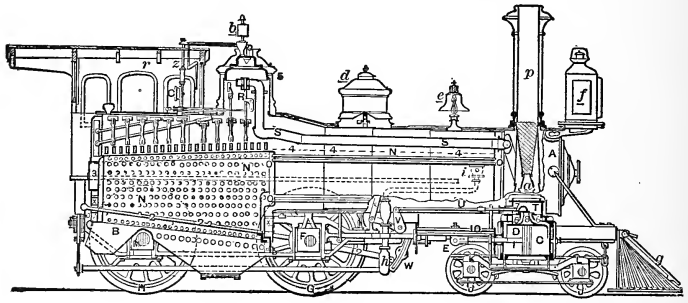


FIG. 11.

fire-box proper by a number of stay-bolts, *X*, *X*. 2, 2 is the grate upon which the fuel is burned, the bottom of the fire-box being open to admit the air necessary for the combustion of the fuel; 3 is the door through which the fuel is admitted. *O*, *O*, show a number of tubes, their purpose being to convey the heated air, or rather products of combustion, through the boiler from the fire-box to the smoke-box *A*. These tubes are of small diameter, and made thin—generally about ⅛ of an inch—so as rapidly to communicate the heat pass-

ing through them to the water by which they are surrounded, and which generally stands about four or five inches above their upper or top row. It is the surface of the fire-box and these tubes that constitute the heating surface of a boiler. That portion of the boiler above the water level—shown by dotted line 4, 4, 4, is the steam-room of the boiler, and is occupied by the steam generated from the water above and among the tubes and in the water space around the fire-box.

The forward compartment of the boiler, or smoke-box, *A*, receives the products of combustion and the chimney *P* provides for its escape into the open air.

The draught of the fire through the tubes is produced artificially by the escape of the steam from the cylinders of the engine through the exhaust pipe *a* into and up the chimney *P*. The peculiar form given to the boiler, the contact of water with the sides and top of the fire-box, and the great extent of fire-surface afforded by the tubes, secure the rapid production of a vast volume of steam within very restricted limits.

The second division of the entire arrangement of the engine is that in which the power already generated is applied to produce motion within the engine itself. Upon the top of the boiler there is a cylindrical chamber 5, called the "dome," and the pipe—called the "steam pipe," which conveys the steam to the cylinders, penetrates it as seen at *R*. The object of elevating the mouth of this pipe is to prevent the motion of the engine from throwing particles of water into it, to be carried to the cylinders and oppose a

dangerous load to the motion of the pistons. The mouth of the steam pipe *SS*, is covered by a valve *R*, called the "throttle valve," provided with ports or openings to admit steam within it, and the admission of steam is governed by the motion communicated to the valve through a rod attached to the throttle lever in the cab, within easy reach of the engineer. In the figure this valve is represented as open and the steam is passing through the pipe, in which it passes along through the partition between the boiler and smoke-box, and down through the branch-pipe (of which there is one to each cylinder), into the steam-chest *T*. This steam-chest communicates with each end of the cylinder *c*, by passages 6 6, called "steam ports," and the steam is admitted through these passages alternately to each end of the cylinder by the "slide-valve" 7. Within the cylinder is a "piston" *D*, against which the steam is exerted to produce motion.

In the position given to the valve as shown in the figure (11,) the right-hand passage is open, and is admitting steam to that end of the cylinder, to press the piston in the opposite direction. There is also a quantity of steam on the left hand of the piston, which was employed in the preceding stroke of the piston to force it to the right hand; and its work now being done, it is escaping through the left hand passage or port, and turning in a cavity in the under side of the valve into a third passage—called the "exhaust port," 8,—on the face of the cylinder, and which is situated midway between the two steam ports already men-

tioned. This steam, called the "exhaust steam," is carried in the last passage a short distance around the cylinder, and passes through an opening on the side of the same into the bottom of a vertical pipe, called the "exhaust pipe" *a*, within the chimney, and from thence escapes to the outer air. The mouth of the exhaust pipe is somewhat contracted, and the resistance given by this contraction to the exit of the steam makes it discharge in a very forcible blast. This powerful draught at the ends of the tubes excites the passage of the heated air through them, and causes a great intensity in the fire. Without this artificial draught, the boiler could not, with its contracted fire surface, generate sufficient steam to supply the cylinders.

We have seen the steam entering by the right-hand passage to the cylinder, and driving the piston to the opposite end of the same. As the piston approaches the left-hand termination of its stroke, the valve 7 is made to shift its position in the steam-chest, and to close the right-hand passage, and at the same time to open the left-hand one. The right-hand passage is fully closed when the piston is within several inches of the end of the cylinder, and the left-hand passage almost at the same time begins to open, so that the full pressure of the steam is exerted against the left-hand side of the piston before it actually has completed its stroke in that direction. This advance of the valve on the piston is called the "lead" of the valve, and when confined within certain limits is found to increase the speed of the engine, as it allows the steam to act with

a concussive force (like that of a spring) at the ends of the strokes, so as to lose no time in changing the motion of the piston. When the piston has commenced its return stroke, and while it is in its motion, the valve moves likewise in the same direction, uncovering the left-hand passage more and more, until, when the piston has returned to the position shown in the figure on the middle of its stroke, this passage is fully open, the same as the right-hand passage, shown in the figure for the preceding stroke. The motion of the valve has transferred the cavity on its under side to the right-hand passage, and the steam, which, during the preceding stroke was admitted through that passage, will now discharge through it and pass into the exhaust port and up the exhaust pipe, as already described. By the time the piston has reached the middle of its stroke, the valve will have reached the end of its motion on the face of the cylinder, and will begin to move in a contrary direction; so that during the last half of the stroke of the piston, the piston and the valve move in opposite directions. The cavity on the under side of the valve in which the steam turns from the steam or induction port into the eduction or exhaust port, must receive such a width of opening as to allow the exhaust steam to *commence* its escape from one end of the cylinder before steam is admitted to the opposite end; so that if, for instance, the lead of the valve on the induction side be $\frac{1}{8}$ of an inch, the exhaust must have a lead of $\frac{1}{4}$ of an inch; or in other words, when one steam port is taking steam

through $\frac{1}{8}$ of an inch, the other must be discharging steam through $\frac{1}{4}$ of an inch. This is necessary for the free escape of the steam, that it may oppose no load to the progress of the piston.

We are now to show how the motion of the piston is communicated to the driving-wheels, and in what manner the slide-valve Z is moved within the steam-chest so as to regulate the admission of the steam to the cylinder; and to guard against any possible misconception on the part of the student, we will here say that there are two steam-chests, two cylinders, and two valves, together with two entire but similar arrangements for communicating the power exerted by the pistons to the wheels. In a few words, a locomotive is nothing more nor less than *two* non-condensing or high-pressure engines, attached to one boiler on wheels. The figure (11) will admit of the representation of but *one* engine—the cylinder, its valve and piston, being one engine, the other being behind the one shown.

Within the centre of the body of the piston *D* is keyed the rod 9 (called the piston-rod), which passes through a "stuffing-box" in the cover of the cylinder, and is attached at its other end to a "cross-head" E, having a pin or bearing for a connecting-rod. This cross-head is also attached to the "guides," 10, to insure the motion of the piston-rod being in the line of the axis of the cylinder. The connecting-rod takes hold of this pin at one end, and at the other to the "crank-pin," which is fitted into the driving-wheels.

As there are two cylinders and two connecting rods, and necessarily two crank pins, these pins are set at right angles to each other, so that one piston may be exerting its entire force against it, while the other is changing the direction of its motion and is exerting but comparatively little power. The alternate motion of the pistons is thus converted into a continuous circular motion, and it is from this motion that the movement for operating the valves is derived, in the following manner: Four eccentrics, the action of which is the same as that of four short cranks, are fixed on the shaft or axle of the forward driving-wheel "between the wheels." There are two eccentrics to each valve, one being set at such an angle with the crank for that cylinder as to give the proper motion to the valve for a forward motion of the engine, and the other set so as to produce a backward motion. These eccentrics are encircled by straps called "eccentric straps," to each of which is attached a rod called the "eccentric-rod" 12, and these rods are joined together by a slotted segment called the "link" W. This link is raised up or lowered down by means of a bar called the "reverse-bar," which is placed within easy reach of the engineer in the cab.

Now when the link is lowered the eccentric-rod of the forward motion, or go-ahead eccentric, comes in line with the valve stem U, and the valve is operated by that eccentric; but when the link is raised the valve is worked by the backing eccentric; and thus the engine is made to run forwards or backwards at will.

It will now be easy to trace the operation of the steam and the machinery put in motion by its action on the piston. The throttle valve at the mouth of the steam pipe *R*, being opened by the lever, the steam will be admitted to the steam-pipe *SS*, and will pass through it, and through the branch-pipe, into the steam-chest. From here it will find its way into the cylinder through whichever passage may be opened by the valve, and drive the piston to one end of the cylinder, by which time the valve will have opened the other port or passage to admit steam to drive the piston back again.

The motion of the piston will be communicated to the driving-wheel through the piston-rod, the connecting-rod and crank-pin and the motion so transmitted will cause the eccentrics to turn, and by their motion the valves will be operated, by means of the link and valve stem. The driving-wheels as they turn will, by their adhesion to the rails, move along the engine and its load; and the constant recurrence of these motions in the piston, valve, and their connections, will maintain the action necessary to produce the required progressive motion of the engine.

Of the remaining parts of the engine show an additional pair of driving-wheels H, connected with the forward drivers by rods called "side-bars," and turning with them.

The object of this second pair of driving-wheels is to obtain a greater adhesion to the rails than could be obtained with only one pair, and also to relieve the prin-

cipal drivers from the great weight of the engine, which would otherwise come upon them—at least all that portion not supported by the truck wheels. The forward drivers generally have plain rims, while the after ones have flanges on their inner sides, like the truck wheels JJ, in order to keep the engine on the rails. The four forward or truck wheels are combined in a separate frame or truck KL, which turns on a spindle secured to the body of the engine, and is used to facilitate the passage of the engine around curves. There are springs over the bearings of the wheels, to relieve the engine from shocks arising from inequalities passed over on the rails. There are pumps or injectors (not shown in the figure), for supplying the boiler with water as fast as it is evaporated in the production of steam. The boiler is provided with one or more safety-valves to allow for the escape of steam when the pressure exceeds the working limit. There are also a whistle *b*, and a bell *e*, for giving signals, and a sand-box *d*, filled with sand, which is generally used to prevent the drivers from slipping when starting a heavy train; a "head-light" *f*, and pilot *G*. From what has been said, the student will be able to understand the principles of the construction and operation of locomotives. The principal feature of engines, including the construction of the boilers and the operation of steam in the cylinders, are the same in all; but there are various modifications in the arrangements of the minor parts, which distinguish the engines by different makers, without affecting, however, the pur-

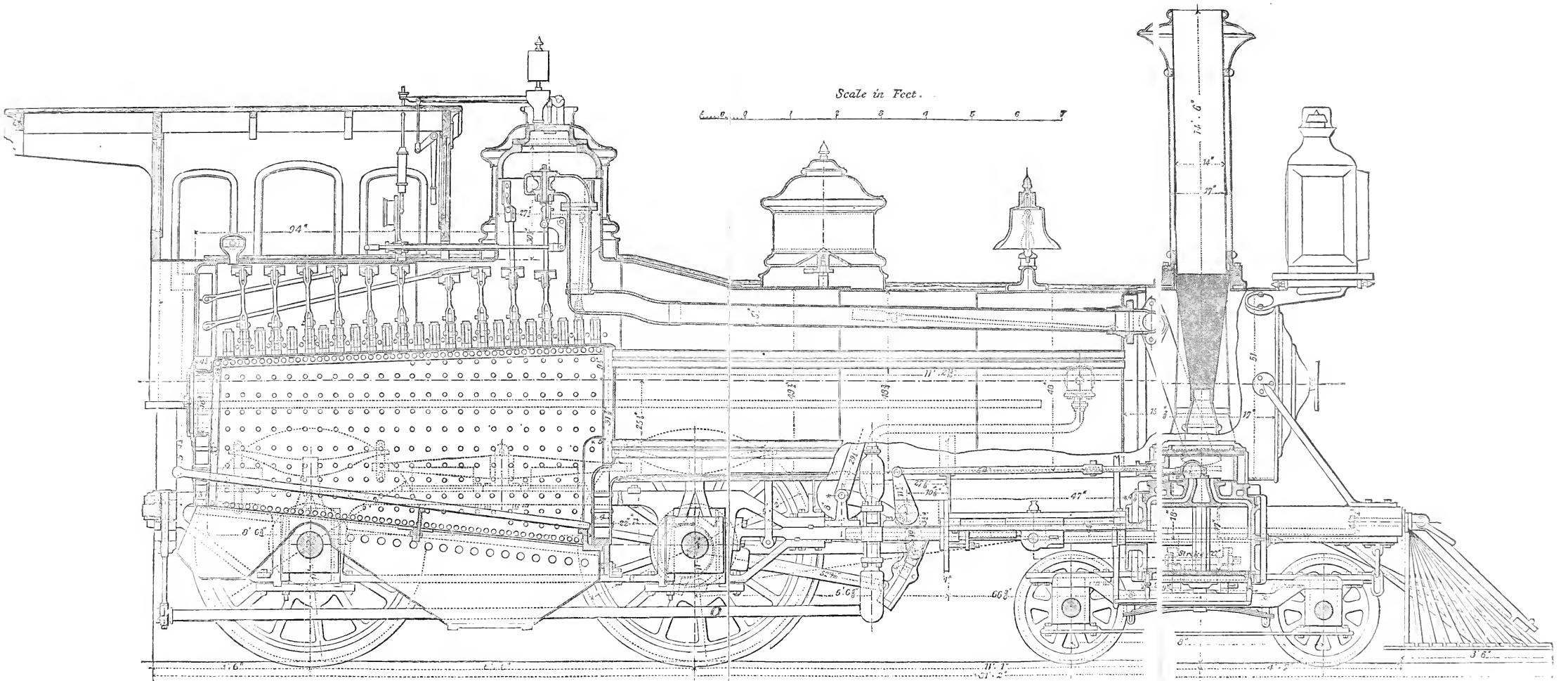


FIG. 12.—STANDARD AMERICAN PASSENGER LOCOMOTIVE.

pose for which they are intended. We will now illustrate and describe a number of standard American locomotives, by which means the student can fully inform himself of the general design and construction of our latest and best American practice.

STANDARD AMERICAN PASSENGER LOCOMOTIVE. (FIG. 12).

As Designed and Constructed by the Baldwin Locomotive Works, Philadelphia, Pa.

The principal dimensions are as follows:

DIMENSIONS.		
Cylinders:	*Feet.*	*Inches.*
Diameter	1	5
Stroke of piston	1	10
Length of steam ports	1	3
Width " "	0	1¼
" of exhaust ports	0	2½
Travel of valve	0	5⅜
Outside lap of valves	0	0¾
Inside " "	0	0$\frac{1}{32}$
Exhaust nozzle—single.		
Wheels:		
Diameter of driving wheels	5	2
" truck wheels.	2	4
Distance between centres of front and rear driving wheels	8	6
Total wheel base of locomotive	22	5
" " " and tender.	44	2½
Diameter of driving axle journals.	0	7
Length " " .	0	8

	Ft.	In.
Wheels.		
Diameter of main crank-pin bearing.	0	4¼
Length " " " .	0	4¼
Boiler:		
Outside diameter of smallest ring of boiler	4	0
Thickness of boiler plate (steel) . .	0	0⅜
Number of tubes—163.		
Length "	11	3
Outside diameter of tubes	0	2
Length of fire-box inside	8	6
Width " "	2	9¾
Depth " " (sloping)—39–53		
Thickness of fire-box plates (steel), side sheets	0	0¼
" " back sheet	0	0 5/16
" " crown sheet	0	0⅜
" " flue sheet	0	0½
Square feet of grate surface—24.		
" " heating surface in fire box—112.		
" " heating surface in tubes—933.		
Total square feet of heating surface—1065.		
Tender:		
Number of wheels—8.		
Diameter "	2	6
" tender-axle journals . .	0	3½
Length " " . .	0	7
Capacity of tank	2200 gallons	

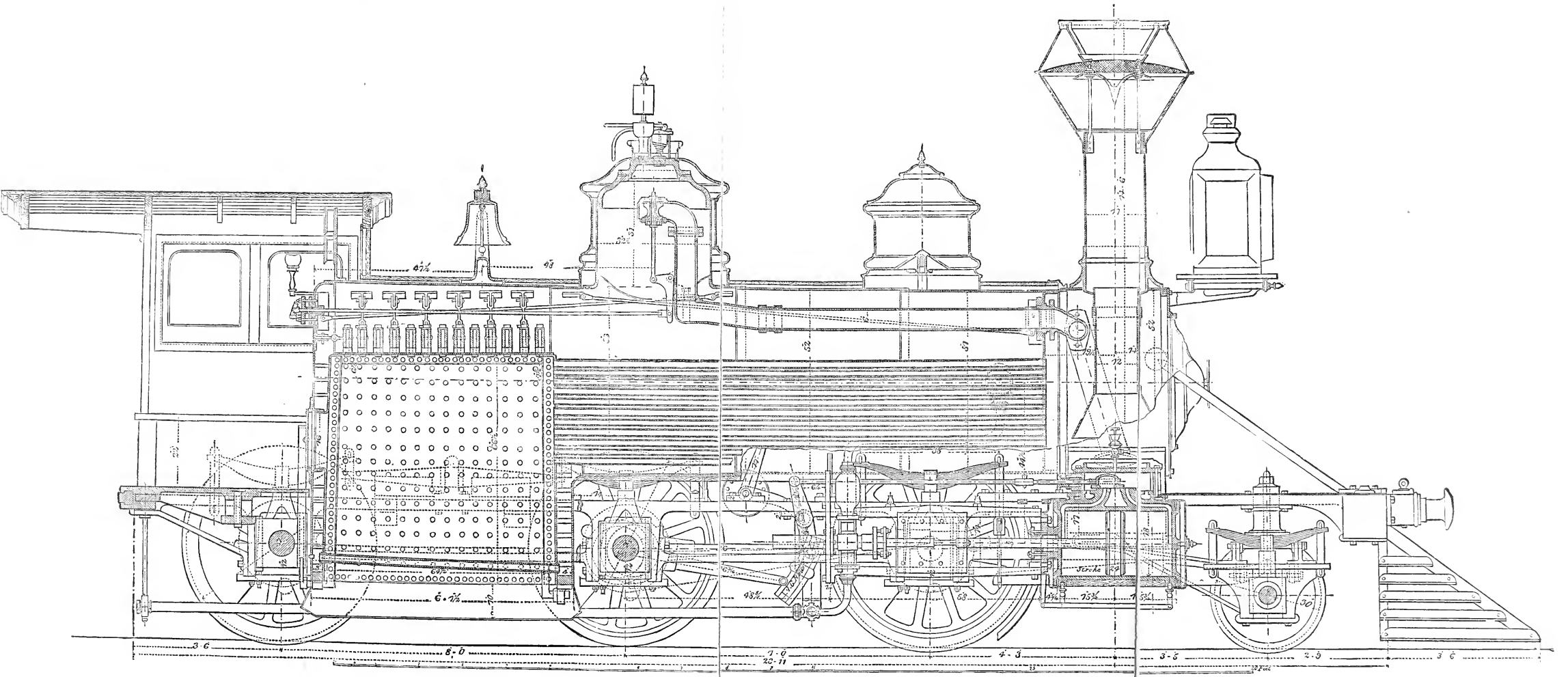


FIG. 13.—STANDARD AMERICAN FREIGHT LOCOMOTIVE. (Page 113.)

Weight:

Weight of engine in working order	75,000 lbs.
" " on driving wheels	51,500 "
" tender, empty	20,500 "

STANDARD AMERICAN FREIGHT LOCOMOTIVE (FIG. 13).

As Designed and Constructed by the Baldwin Locomotive Works, Philadelphia, Pa.

The principal dimensions are as follows:

Cylinders:	*Ft.*	*In.*
Diameter	1	6
Stroke of pistons	2	0
Length of steam ports	1	4
Width " "	0	1¼
" of exhaust ports	0	2½
Travel of valves	0	5⅜
Outside lap of valves	0	0¾
Inside " "	0	0$\frac{1}{32}$
Exhaust nozzles—double, variable.		
Wheels:		
Diameter of driving-wheels	4	6
" " truck wheels	2	6
Distance between centres of front and rear driving-wheels	15	0
Total wheel-base of locomotive . .	22	8
" " " and tender	44	3
Diameter of driving-axle journals .	0	7
Length " " .	0	8
Diameter of main crank-pin bearing	0	4½
Length " "	0	4½

Boiler:	*Ft.*	*In.*
Outside diameter of smallest ring of boiler	4	3
Thickness of boiler-plates (iron)	0	0½
Number of tubes	159	
Length "	11	2¾
Outside diameter of tubes	0	2
Length of fire-box inside	5	5
Width " "	2	11½
Depth " "	5	3½
Thickness of fire-box plates (copper), side, back, and front sheets	0	0½
Thickness of flue-sheet	0	0⅞
" crown-sheet (steel)	0	0⅜
Square feet of grate-surface	16	
" " heating surface in fire-box	103	
" " heating surface in tubes	937	
Total square feet of heating surface	1040	
Tender:		
Number of wheels	8	
Diameter "	2	4
" tender axle journals	0	3¼
Length " "	0	7
Capacity of tank	2000 gallons.	
Weight:	*Lbs.*	
Weight of engine in working order	80,000	

Weight:	*Lbs.*
Weight of engine on driving-wheels	68,000
Weight of tender, empty . .	20,000

CONSOLIDATION LOCOMOTIVES OF THE PHILADELPHIA AND READING RAILROAD.

These engines have the Wootten fire-box, for burning fine coal. It extends laterally over the frames and back pair of driving-wheels, so as to be 8 feet wide inside.

The following are the principal dimensions of these engines:

Cylinders, 20 in. diameter × 24 in. stroke.
Driving-wheels, 50 in. diameter.
Truck-wheels, 30 in. diameter.
Driving-wheel base, 14 ft. 9 in.
Total wheel-base, 22 ft. 10 in.
Fire-box, 114 in. long × 96 in. wide.
Smallest diameter of boiler, 56 in.
197 tubes, 2 in. diameter × 11 ft. 6½ in. long.
Heating surface in tubes, 1,190 sq. ft.
Heating surface in fire-box, 167 sq. ft.
Heating surface, total, 1,357 sq. ft
Grate consists of water-tubes and cast-iron bars.
Driving-wheel journals, 7 × 8 in.
Truck-wheel journals, 5 × 8 in.
Steam-ports, 16 in. × 1¼ in.
Exhaust-ports, 16 in. × 2½ in.
The boiler is fed by two No. 8 Sellers injectors.
Capacity of tank, 2,800 gallons.

Diameter of tender-wheels, 30 in.

Journals of tender, 3⅞ in. diameter × 8 in. long.

The fire-box slopes downward, and is stayed on top and sides with stay-bolts.

The engines also have feed-water heaters, which are shown under the running board.

The excellent performance of this engine will be seen from the following accounts of recent trial trips:

A trial trip of one of these locomotives in ordinary freight service on the Bound Brook Line, between Philadelphia and New York, June 22, 1880.

The locomotive left Third and Berks streets depot, Philadelphia, at 9 A. M., empty, and at Fairhill Junction took on fifty loaded four wheeled cars, at Jenkintown took thirty more, and at Bound Brook added twenty more, making a train of one hundred loaded four-wheeled cars, with which it arrived at Elizabethport at 5 P. M.. The tank was full of water on leaving Philadelphia and was refilled three times.

Fairhill Junction to Jenkintown, maximum grade, 58.6 feet per mile; train, 50 loaded four-wheeled cars.

Jenkintown to Bound Brook, maximum grade, 37 feet per mile; train, 80 loaded four-wheeled cars.

Bound Brook to Elizabethport, maximum grade, 23 feet per mile; train, 100 loaded four-wheeled cars.

Quantity of water consumed . . 7,747 gallons.
Whole time on road . . . . . 8 hours.
Actual running time with train,
Fairhill Junction to Elizabethport . . . . . 5 hours 43 min.
Weight of each loaded car . . $8\frac{11}{20}$ gross tons.

Returning, the engine left Elizabethport with 119 empty four-wheeled cars at 6 P. M., and arrived at Third and Berks streets, Philadelphia, at 12:10 P. M. The tank was full of water on leaving Elizabethport, and was refilled three times.

Quantity of water consumed	6,215 gallons.
Whole time on road	6 hours 10 min.
Actual running time, Elizabethport to Philadelphia	4 hours 32 min.
Maximum grade of road	37 feet per mile.
Weight of each empty car	$3\frac{8}{20}$ gross tons.

SUMMARY.

Distance (77½ miles each way)	155 miles.
Total weight of coal consumed in round trip, including firing up,	13,900 pounds.
Coal consumed in firing up and in furnace at end of trip, estimated,	950 pounds.
Coal consumed in making round trip	12,950 pounds.
Total quantity of water consumed in round trip	13,962 gallons.
Pounds of water evaporated per pound of coal	8.98

The engine steamed very freely all the while. The safety valve, set at 127 pounds, blew off frequently when running, although the engine ran much of the time with the register in smoke-box front open, and with the furnace doors open. When coming to stations the pressure was reduced to 100 pounds by opening the furnace doors, and in a few minutes after closing

the doors the pressure would rise to 127 pounds. The engine made very little smoke or cinders, and at night very few sparks were noticeable.

A run was made August 17, 1880, with Consolidated engine No. 417, of the Philadelphia and Reading Railroad Company, from Fairhill Junction to Elizabethport and return, using Youghiogheny bituminous coal. The performance was as follows:

EASTWARD TRIP.

Train, Fairhill Junction to Jenkintown. 56 loaded four-wheeled cars.
Train, Jenkintown to Elizabethport . . . 81 " " "
Quantity of water used, 7,865 gallons.

WESTWARD TRIP.

Train, Elizabethport to Fairhill Junction, 112 empty four-wheel cars.
Quantity of water used, 6,297 gallons.

SUMMARY.

Total weight of coal consumed in round trip, including firing up . 13,808 pounds.
Coal consumed in firing up . . . 1,275 "
Coal consumed in making round trip . . . . . 12,533 "
Total quantity of water used in round trip . . . . . 14,162 gallons.
Pounds of water evaporated per pound of coal 9.41

The standard passenger engines of the Pennsylvania

Railroad have four driving-wheels 5½ feet in diameter; steam cylinders 17 inches in diameter, and 24 inches stroke; grate surface 15½ square feet; heating surface 1,058 square feet. They weigh each 63,000 pounds, of which 39,000 pounds are on the drivers, and 24,000 pounds on the truck wheels. The standard freight engines of the same road, have six driving wheels 54⅝ inches in diameter. The steam cylinders are 18 inches in diameter and 22 inches stroke; grate surface $14\frac{8}{10}$ square feet; heating surface 1,096 square feet. They weigh each 68,500 pounds, of which 48,000 pounds are on the drivers, and 20,500 pounds on the truck wheels.

The average American locomotive has a maximum life of about 30 years. The annual cost of repairs is from 10 to 15 per cent. of the first cost. Each engine requires about one pint of oil for each 25 miles run, and one ton of coal for each 40 or 50 miles run.

CHAPTER X.

LOCOMOTIVES AT THE CENTENNIAL EXHIBITION, PHILADELPHIA, 1876.

THE show of Locomotives at the Centennial Exhibition was essentially an American one, for with the single exception of the small Swedish engine shown, they were all of American design and construction.

The following outline, figures Nos. 14 to 31 inclusive, shows every engine shown in the building. The figures are all drawn to the same scale, so that they not only convey a fair idea of the general arrangement of the engines, but also of their relative sizes. The following table, with notes referring to the same, will prove of value as regards designs, the proportions of the different parts, and the materials used in construction. Indeed, it can be safely said that in these outline figures and accompanying table the latest and best practice of American Locomotive Engineering can be seen at a glance.

In conjunction with these examples, the student should familiarize himself with the general design and proportions of the various parts of any and every locomotive he may inspect. This information can be easily obtained by actual measurement, and from the engineer in charge, all of which should be noted in a note-book.

Fig. 14

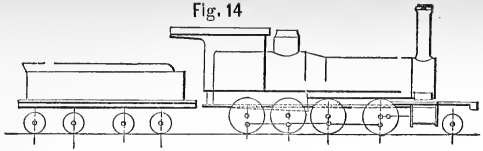


Fig. 15

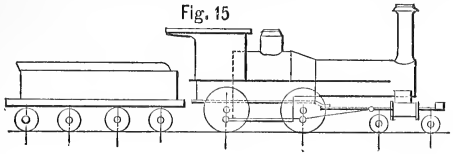


Fig. 16

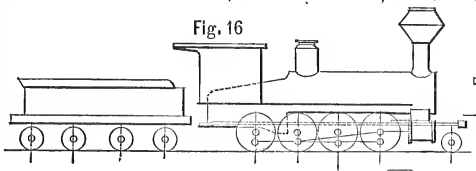


Fig. 17

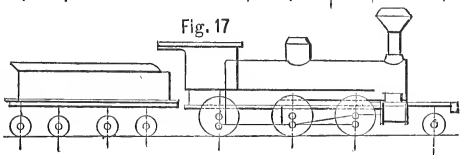


Fig. 18

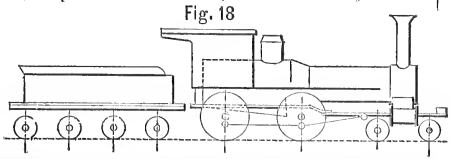


Fig. 19

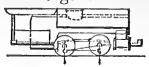


Fig. 20

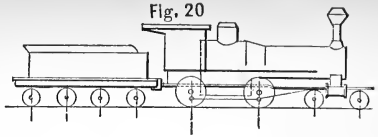


Fig. 21

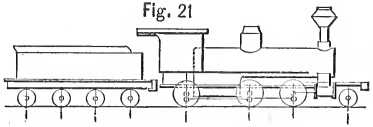


Fig. 22

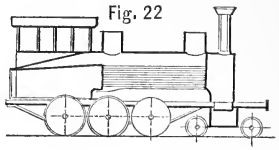


Fig. 23

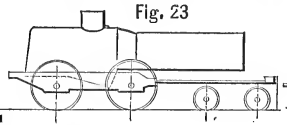


Fig. 24

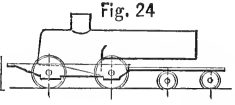


Fig. 25

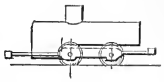


Fig. 26

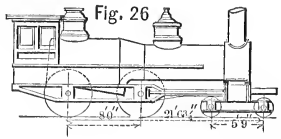


Fig. 27

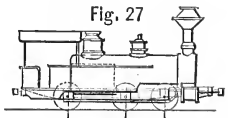


Fig. 28

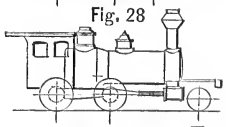


Fig. 30

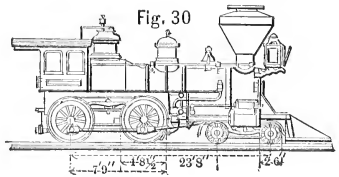
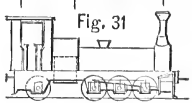


Fig. 31



LOCOMOTIVES AT THE CENTENNIAL EXHIBITION.—TABLE OF LEADING PARTICULARS.

No.	REFERENCE NUMBERS OF DIAGRAMS	14	15	16	17	18	19	20	21	22
1	Name and address of manufacturer	Burnham, Parry, Williams, and Co., Baldwin Locomotive Works, Philadelphia, Pa.								Philadelphia & Reading R.R.
2	Railroad for which engine is built	Lehigh Valley Railw'y	Pennsylvania Railroad		Dom Pedro II Railr'd Brazil	Central Railr'd of New Jersey		West End Railroad,	Passenger Cent'nial	Ditto.
3	Whether passenger or freight engine.	Freight	Passenger	Freight	Freight	Passenger	Mining	Passenger	Freight (*c*)	Fast freight
4	Whether tender or tank engine	Tender	Tender	Tender	Tender	Tender	Tank	Tender	Tender	Tender
5	Width of gauge	4 ft. 8 1-2 in.	4 ft. 9 in.	4 ft. 9 in.	5 ft. 3 in.	4 ft. 8 1-2 in.	3 ft. 6 in.	3 ft. 0 in.	3 ft. 0 in.	4 ft. 8 1-2 in.
	WHEELS:									
6	Number of wheels	10	8	10	8	8	4	8	8	10
7	Number of coupled wheels	8	4	8	6	4	4	4	6	6
8	Diameter of coupled wheels	50 3-4 in.	62 in.	50 in.	54 in.	62 in.	30 in.	42 in.	37 in.	54 in.
9	Diameter of wheels, other than truck wheels, not coupled	...	...	...	...	...	...	...	...	...
10	Total wheel base	22 ft. 10 in.	22 ft. 6 in.	22 ft. 4 in.	22 ft. 8 in.	22 ft. 5 in.	3 ft. 10 in.	18 ft. 7 in.	17 ft. 8 in.	20 ft. 5 in.
11	Length of rigid wheel base	14 ft. 9 in.	8 ft. 6 in.	13 ft. 8 in.	15 ft. 0 in,	8 ft. 6 in.	3 ft. 10 in.	7 ft. 6 in.	11 ft. 8 in.	17 ft. 5 in.(*e*)
12	If with truck in front	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
13	Type of truck	Bissell	Swing	Swing	Swing	Swing	...	Swing	Swing	Centre bearing
14	Number of wheels in truck	2	4	2	2	4	...	4	2	4
15	Diameter of " "	30 in.	28 in.	28 in.	30 in.	28 in.	...	24 in.	24 in.	30 in.
16	Materials of main wheels	See Note (*f*)		...	...	...	...	...	...	...
17	Material of truck wheels	...	Chilled	cast iron	...	See Note (*g*)	...	Chilled	cast iron	Chilled castiron
	AXLES AND CRANK BEARINGS:									
18	Diameter of bearing of driving axle.	7 in.	7 in.	6 1-2 in.	7 in.	7 in.	4 in.	5 1-2 in.	5 in.	6 1-8 in.
19	Length of " "	8 in.	7 3-8 in.	7 1-2 in.	8 in.	8 in.	6 in.	7 in.	7 in.	8 in.
20	Diameter of main crank-pin bearing	5 in.	3 3-4 in.	4 1-2 in.	4 1-2 in.	4 1-4 in.	2 1-4 in.	3 1-4 in.	3 1-4 in.	4 1-4 in.
21	Length of " "	5 in.	3 3-4 in.	5 in.	4 1-2 in.	4 1-4 in.	3 in.	3 1-2 in.	3 1-2 in.	4 in.
	CYLINDERS:									
22	Position of cylinders	Outside	Outside	Outside	Outside	Outside	Outside	Outside	Outside	Outside
23	Diameter of "	20 in.	17 in.	20 in.	18 in.	17 in.	8 in.	12 in.	12 in.	18 in.
24	Length of stroke	24 in.	24 in.	24 in.	24 in.	22 in.	12 in.	16 in.	16 in.	24 in.
	VALVES AND VALVE GEAR:									
25	Length of steam ports	16 in.	16 in.	17 1-4 in.	16 in.	15 in.	7 1-2 in	10 in.	10 in.	15 in.
26	Width of "	1 1-4 in.	1 1-4 in.	1 1-4 in.	1 1-4 in.	1 1-4 in	5-8 in	1 in	1 in.	1 1-4 in.

No.	REFERENCE NUMBERS OF DIAGRAMS	14	15	16	17	18	19	20	21	22
27	Width of exhaust port	2 1-2 in.	2 1-2 in.	2 1-2 in.	2 1-2 in.	2 1-2 in.	1 1-4 in.	2 in.	2 in.	2 1-2 in.
28	Outside lap of valve	3-4 in.	3-4 in.	3-4 in.	3-4 in.	3-4 in.	7-16 in.	5-8 in.	9-16 in.	3-8 in.
29	Inside " "	1-12 in.	0	0	1-32 in.	1-32 in.	1-32 in.	1-32 in.	1-32 in.	...
30	Trave of valve	5 3-4 in.	5 in.	5 in.	5 3-8 in.	5 3-8 in.	2 1-2 in.	4 1-2 in.	4 1-2 in.	4 1-2 in.
31	Throw of eccentrics	5 in.	5 in.	5 in.	5 in.	5 in.	2 in.	4 1-2 in.	3 1-2 in.	3 3-4 in.
32	Type of valve gear	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link
33	Position of "	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe
	BOILER AND FIREBOX:									
34	Maximum internal diameter of boiler	57 in.	51 1-4 in.	55 3-8 in.	53 in.	50 1-4 in.	24 5-8 in.	43 1-2 in.	39 1-2 in.	50 in.
35	Minimum " " "	53 in.	48 3-4 in.	53 1-2 in.	50 in.	47 1-4 in.	23 3-8 in.	41 1-4 in.	37 1-4 in.	46 in.
36	Height of centre of boiler above rails	6 ft. 4 3-16 in.	6 ft. 2 in.	6 ft. 5 in.	6 ft. 1 1-4 in.	6 ft. 2 1-4 in.	3 ft. 4 1-2 in.	5 ft. 2 in.	4 ft. 9 1-4 in.	6 ft. 5 1-2 in.
37	Length of firebox inside at bottom	9 ft 10 in.	6 ft. 0 5-8 in.	8 ft. 0 in.	5 ft. 5 in.	8 ft. 6 in.	2 ft. 5 1-4 in.	4 ft. 11 in.	4 ft. 6 1-4 in.	8 ft. 0 in.
38	Width of " " "	2 ft. 9 7-8 in.	2 ft. 10 7-8 in.	2 ft. 10 1-2 in.	2ft. 11 1-2 in.	2 ft. 9 3-4 in.	2 ft. 0 3-4 in.	1 ft. 9 1-2 in.	1 ft. 10 1-2 in.	3 ft. 6 in.
39	Height of firebox crown above grate	38 1-2 in. and 50 in. (k)	58 in. and 62 in. (k)	36 in. and 55 in. (k)	56 1-2 in. & 59 1-2 in. (k)	32 1-2 in and 47 in. (k)	2 ft. 6 in.	3 ft. 11 in.	3 ft. 9 in.	30 ft. & 43 ft. (l)
40	Number of tubes	198	155	188	159	162	43	112	124	198
41	Outside diameter of tubes	2 in.	2 1-4 in.	2 1-2 in.	2 in.	2 in.	1 1-2 in.	2 in.	1 1-2 in.	1 3-4 in.
42	Inside " "	1.782 in.	2.032 in.	2.282 in.	1.782 in.	1.782 in.	1.334 in.	1.782 in.	1.334 in.	1 1-2 in.
43	Length of tubes between tube plates	10 ft. 11 in.	10 ft. 7 in.	12 ft. 10 in.	11 ft. 1 3-4 in.	11 ft. 2 in.	6 ft. 3 in.	8 ft. 4 1-4 in.	8 ft. 0 1-4 in.	11 ft. 6 in.
44	Boiler material	Iron	Steel	Steel	Iron	Steel	Iron	Iron	Iron	Iron
45	Thickness of boiler plates	1-2 in.	3-16 in.	3-4 in.	1-2 in.	5-8 in.	5-16 in.	3-4 in.	3-8 in.	3-8 in. & 1-2 in.
46	Tube material	Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron
47	Thickness of tubes	.109 in.	.109 in.	.109 in.	.109 in.	.109 in.	.083 in.	.109 in.	.083 in.	1-8 in.
48	Firebox material	Steel 3-16in.	Steel 3-16in.	Steel3-16 in.	Copper 3-4 in.	Steel (o)	Steel 1-4 in.	Steel3-16 in.	Steel	Steel
	HEATING SURFACES:	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
49	Heating surface of firebox	112	106	92	103	112	24	72	60	86
50	External surface of tubes	1131	971	1159	927	953	106.5	490	391	1042
51	Internal " "	217	271	1057	826	848	93.8	436	347	894
52	Total heating surface with external tube surface	1243.0	1077.0	1251.0	1030.0	1065	130.5	562	451	1128.0
53	Total heating surface with internal tube surface	1119.0	977.0	1149.0	929.0	960.0	117.8	508.0	407.0	980.0
54	Firegrate area	24	18	23 1-4	16	24	5	8.5	8.5	28
55	Flue area through full sectional area of tubes	sq. in. 503.	sq. in. 502.20	sq. in. 565.6	sq. in. 395.9	sq. in. 405.87	sq. in. 60.2	sq. in. 278.88	sq. in. 173.6	sq. in. 349.86
56	Number of internal diameters in length of tube	73.3	62.5	67.5	75.0	75.2	56.1	56.25	72.15	92.0
57	External tube surface divided by firebox surface	10.10	9.16	12.60	9.00	8.51	4.44	6.06	6.62	12.12
58	Total heating surface divided by firegrate area	51.79	59.83	53.80	64.37	44.37	26.10	66.12	53.05	40.28
59	Firegrate area divided by flue area	6.87	5.61	5.92	5.14	8 51	11.96	4.39	7.05	11.52

No.	REFERENCE NUMBERS OF DIAGRAMS	14	15	16	17	18	19	20	21	22
	WEIGHTS OF ENGINE:									
60	Weight of engine empty	...	...	...	...	...	...	...	..	69,900 lb.
61	Weight of engine in working order	100,000 lb.	71,900 lb.	91,640 lb.	80,000 lb.	75,000 lb.	15,000 lb.	42,000 lb.	35,000 lb.	78,832 lb.
62	Weight on coupled wheels in working order	88,000 lb.	45,800 lb.	79,400 lb.	68,000 lb.	51,500 lb.	15,000 lb.	28,000 lb.	35,000 lb.	53,536 lb.
63	Weight empty per square foot of heating surface	...	...	...	...	...	...	...	...	61.9
	MISCELLANEOUS:									
64	Contents of coal tanks	...	...	...	...	...	...	...	...	...
65	Contents of water tanks	...	...	...	...	...	158 gals. Eng.	...	...	...
66	Diameter of blast nozzle	Variable	2 1-2 in. by 3 1-2 in. (*u*)	3 in. by 3 3-4 in. (*u*)	Variable	4 1-4 in. (*v*)	2 1-2 in. (*v*)	2 1-4 in. (*u*)	2 1-4 in. (*u*)	Variable(*w*)
67	Maximum diameter of chimney	18 in.	18 in.	20 in.	17 in.	14 in.	5 1-2 in.	10 in.	10 in.	14 in.
68	Minimum " "	16 in.	18 in.	20 in.	17 in.	14 in.	5 1-2 in.	10 in.	10 in.	14 in.
69	Least sectional area of chimney in square inches	201.06	254.47	314.16	226.98	153.94	23.76	78.54	78.54	153.94
70	Firegrate area divided by least sectional area of chimney	17.1	10.18	10.65	10.15	22.45	30.95	15.58	15.58	26.19
71	Working pressure of steam in pounds per square inch	130 lb.	...	...	130 lb.	130 lb.	110 lb.	125 lb.	125 lb.	110 lb.
72	Nature of fuel used	Anthracite	Bituminous	Bit. coal	Bit. coal	Anthracite	Anthracite	Anthracite	Anthracite	Anthracite
73	Tractive force for each pound of effective pressure per square inch on pistons	190.6	111.9	192	144	102.55	25.6	54.85	62.27	144
74	Tractive force with an effective pressure on the pistons equal to four-fifths the boiler pressure	25,022	...	...	14,976	10,665	2,252.8	5,485	6,227	12,672
75	Tractive force in previous line expressed in per cent. of adhesion weight	28.20	...	...	22.02	20.71	15.02	19.59	17.78	23.67
	TENDER:									
76	Number of wheels in tender	8	8	8	8	8	...	8	8	8
77	Diameter of " "	30 in.	33 in.	30 in.	28 in.	30 in.	...	24 in.	24 in.	30 in.
78	Material of " "	Chilled castiron	Chilled castiron	Chilled castiron	Chilled castiron	C.I. Stl. tyres (*a a*)	...	Chilled castiron	Chilled castiron	Chilled castiron
79	Contents of coal space	...	...	...	...	...	...	...	...	12,000 lb.
80	Contents of water tanks, Eng. gals.	...	2000	2000	1666	1833	...	834	1000	1936
		14	15	16	17	18	19	20	21	22

LOCOMOTIVES AT THE CENTENNIAL EXHIBITION.—TABLE OF LEADING PARTICULARS.—*Continued.*

No.	REFERENCE NUMBERS OF DIAGRAMS	23	24	25	26	27	28	29	30	31
1	Name and address of manufacturer	The Dickson Manufacturing Company, Scranton, Pa.			Danforth Locomotive Works, Paterson, N.J.		Porter, Bell, & Co., Pittsb'g, Pa.	W Mason Taunton Mass.	Rogers Loco. Machine Works, Patterson, N. J.	Dannemora Hary's Jernvay, Sweden.
2	Railroad for which engine is built	...	...	..	...	...	...	W. End Pas. Ry. C. Grds.	Mobile & Montg'y Rld.	*b*
3	Whether passenger or freight engine.	Passenger	Passenger	Mining	Passenger	Freight	Passenger	Passenger &	Mixed	
4	Whether tender or tank engine	Tender	Tender	Tank	Tender	Tank	Tender	Tank	Tender	Tank
5	Width of gauge	4 ft. 8 1-2 in.	4 ft. 8 1-2 in.	3 ft. 0 in.	4 ft. 8 1-2 in.	3 ft. 0 in.	3 ft. 0 in.	3 ft. 0 in.	5 ft. 0 in.	3 ft. 3 1-8 in.
	WHEELS:									
6	Number of wheels	8	8	4	8	6	6	8	8	8
7	Number of coupled wheels	4	4	4	4	6	4	4	4	6
8	Diameter of coupled wheels	67 in.	42 in.	29 in.	62 3-8 in.	36 in.	44 in.	36 in.	56 1-2 in. (cc)	31 1-2 in.
9	Diameter of wheels, other than truck wheels, not coupled	...	...	...	...	...	...	...	...	29 1-2 in.
10	Total wheel base	21 ft. 10 in.	17 ft. 6 in.	4 ft. 6 in.	21 ft. 6 1-4 in.	10 ft. 10 in.	16 ft. 2 in.	21 ft. 8 1-2 in.	21 ft. 8 in.	12 ft. 2 in.
11	Length of rigid wheel base	8 ft. 0 in.	6 ft. 8 in.	4 ft. 6 in.	8 ft. 0 in.	10 ft. 10 in.	6 ft. 0 in.	...	7 ft. 9 in.	5 ft. 10 in.
12	If with truck in front	Yes	Yes	No	Yes	No	Yes	Two trucks	Yes	No
13	Type of truck	Swing	Swing	...	Centre bearing	...	Swing	Fairlie system	**Swing**	
14	Number of wheels in truck	4	4	...	4	...	2	4 each truck	4	
15	Diameter of " "	30 in.	24 in.	...	28 in.	...	30 in.	37 in.	26	
16	Materials of main wheels	Cast iron bo	dies and ste	el tyres	Cast iron an	d steel tyres	C. I. & st. ty.	...	C.I. centre &	steel tyres
17	Material of truck wheels	Chilled	cast iron	...	Chilled castiron	...	Chilled castiron	..	Chilled castiron	
	AXLES AND CRANK BEARINGS:									
18	Diameter of bearing of driving axle.	7 in.	5 in.	4 1-2 in.	6 1-2 in.	4 1-2 in.	5 3-16 in.	5 1-2 in.	6 1-2 in.	3 3-4 in
19	Length of " "	8 1-2 in.	6 1-2 in.	6 in.	7 7-8 in.	6 in.	5 1-2 in.	7 in.	7 1-2 in.	5 3-4 in
20	Diameter of main crank-pin bearing	4 1-4 in.	3 in.	3 in.	4 in.	3 in.	3 1-4 in.	3 in.	3 3-4 in.	3 in.
21	Length of " "	4 in.	3 1-4 in.	3 in.	3 3-4 in.	2 1-2 in.	3 1-4 in.	3 in.	3 3-4 in.	3 in.
	CYLINDERS:									
22	Position of cylinders	Outside	Outside	Outside	Outside	Outside	Outside	Outside	Outside	Outside
23	Diameter of "	17 in.	11 in.	9 in.	17 in.	11 in.	11 in.	11 in.	16 in.	11 in.
24	Length of stroke	24 in.	16 in.	12 in.	24 in.	16 in.	16 in.	16 in.	24 in.	16 in.
	VALVES AND VALVE GEAR:									
25	Length of steam ports	16 in.	9 1-2 in.	6 in.	15 1-2 in.	8 in.	...	9 in.	14 1-2 in.	6 1-2 in
26	Width o' '	1 1-4 in.	1 in.	13-16 in.	1 1-4 in.	3-4 in.	...	1 1-2 in.	1 7-32 in.	1 in

No.	REFERENCE NUMBERS OF DIAGRAMS	23	24	25	26	27	28	29	30	31
27	Width of exhaust port	2 1-2 in.	2 in.	1 1-2 in.	2 1-4 in.	1 1-2 in.	...	2 1-2 in.	2 1-2 in.	2 in.
28	Outside lap of valve	3-4 in	5-8 in.	5-8 in.	3-4 in.	5-8 in.	...	13-16 in.	3-4 in.	
29	Inside " "	1-64 in.	...	...	1-16 in.	...	...	1-32 in.	3-32 in. [*dd*]	
30	Travel of valve	...	...	...	...	...	...	4 in.		
31	Throw of eccentrics	4 3-4 in.	4 1-2 in.	3 in.	5 1-2 in.	3 1-2 in.	...	7 in. [*h*]	5 in.	
32	Type of valve gear	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Shifti'g link	Walschaert	Shifti'g link	
33	Position of "	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Insideframe	Outside	Insideframe	Outside
	BOILER AND FIREBOX:									
34	Maximum internal diameter of boiler	49 in.	33 5-8 in.	29 1-4 in.	48 in.	36 1-2 in.	43 3-8 in. (*i*)	38 5-8 in.	48 7-16 in.	34 7-8 in.
35	Minimum " "	48 in.	33 in.	28 5-8 in.	46 1-8 in.	35 1-4 in.	36 3-4 in. (*j*)	35 1-4 in.	47 in.	
36	Height of centre of boiler above rails	6 ft. 5 in.	4 ft. 11 in.	3 ft. 6 1-2 in.	5 ft. 11 1-2 in.	4 ft. 4 1-4 in.	4 ft. 11 in.	4 ft. 10 1-2 in.	5 ft. 10 3-4 in.	4 ft. 8 in.
37	Length of firebox inside at bottom	8 ft 9 in.	6 ft. 0 in.	2 ft. 10 in.	8 ft. 0 in.	4 ft. 6 in.	3 ft. 10 1-2 in.	3 ft. 8 in.	6 ft. 0 in.	2 ft. 6 in.
38	Width of " "	2 ft. 9 3-4 in.	1 ft. 8 1-2 in.	1 ft. 11 3-4 in.	2 ft. 10 5-8 in.	1 ft. 5 in.	1 ft. 7 1-2 in.	2 ft. 9 in.	2 ft. 11 in.	3 ft. 0 1-2 in.
39	Height of firebox crown above grate	4 ft. 1 1-2 in.	2 ft. 11 1-2 in.	2 ft. 4 1-4 in.	{35 in. & 46 1-2 in (*l*)}	3 ft. 1 in.	3 ft. 4 in.	3 ft. 9 in.	{66 3-4 in. & 58 1-2 in. [*ee*]}	
40	Number of tubes	163	92	66	175	92	120	88	154	
41	Outside diameter of tubes	2 in.	1 1-2 in.	1 1-2 in.	2 in.	1 3-4 in.	1 3-4 in.	2 in.	2 in.	
42	Inside " "	1 13-16 in.	1 5-16 in.	1 5-16 in.	1.80	1.56	1 1-2 in.	1 3-4 in.	1 3-4 in.	
43	Length of tubes between tube plates	11 ft. 6 in.	8 ft. 8 1-2 in.	7 ft. 4 3-4 in.	10 ft. 5 1-8 in.	6ft. 11 1-8 in.	7 ft. 11 in.	8 ft. 11 in.	10 ft. 1 in.	8 ft. 11 in.
44	Boiler material	Iron	Iron	Iron	Iron	Iron	Iron (*m*)	Iron	Iron	
45	Thickness of boiler plates	{3-4 in. & 7-16 in.}	{5-16 in & 3-8 in.}	{5-16 in & 3-8 in.}	{5-8 in. & 7-16 in (*r*)}	3-4 in.	{5-16 in & 3-8 in (*s*)}	3-8 in.	3-8 in.	
46	Tube material	Iron (*n*)	Iron (*n*)	Iron (*n*)	Iron	Iron	Iron	...	Iron, lap wd	
47	Thickness of tubes	3-32 in.	5-32 in.	5-32 in.	.10	.095	I-8 in.	1-8 in.	1-8 in.	
48	Firebox material	Steel	Steel	Steel	{Steel 5-16 in. (*p*)}	{Steel 5-16 in. (*p*)}	{Steel 5-16 in. [*q*]}	Steel	{Steel 5-16 in. (*ff*)}	
	HEATING SURFACES:									
49	Heating surface of firebox	sq. ft. 118.1	sq. ft. 63.75	sq. ft. 32	sq. ft. 101.5 (*t*)	sq. ft. 49	sq. ft. 55	sq. ft. 56.7	sq. ft. 87	
50	External surface of tubes	974.4	314.5	188.7	954.26	291.5	434	410	813	
51	Internal " "	887	274	164	860	260.2	373	359	711	
52	Total heating surface with external tube surface	1092.5	378.25	220.7	1055.76	340.5	489	466.7	900	
53	Total heating surface with internal tube surface	1005.0	337.75	196.0	961.6	309.2	428.0	415.7	798.0	
54	Firegrate area	24.14	10.25	5.6	22.96	6.34	6.33	10	14.40	7.5 sqr. ft.
55	Flue area through full sectional area of tubes	sq. in. 426.24	sq. in. 129.6	sq. in. 90.72	sq. in. 444.5	sq. in. 275	sq. in. 212	sq. in. 211	sq. in. 370	
56	Number of internal diameters in length of tube	76.16	79.1	67.6	69.51	53.28	63.3	61.1	69.1	
57	External tube surface divided by firebox surface	8.25	4.93	5.59	9.40	5.95	7.89	7.2	9.35	
58	Total heating surface divided by firegrate area	42.26	36.90	39.41	45.98	53.70	77.26	46.67	62.51	
59	Firegrate area divided by flue area	8.15	11.39	8.88	7.44	3.32	4.29	7.82	5.60	

No.	REFERENCE NUMBERS OF DIAGRAMS	23	24	25	26	27	28	29	30	31
	WEIGHTS OF ENGINE:									
60	Weight of engine empty	67,500 lb.	36,400 lb.	15,900 lb.	...	27,225 lb.	27,000 lb.	...	64,500 lb.	
61	Weight of engine in working order	71,000 lb.	39,000 lb.	18,900 lb.	...	37,000 lb.	32,000 lb.	...	62,000 lb.	
62	Weight on coupled wheels in working order	47,000 lb.	26,500 lb.	18,900 lb.	...	37,000 lb.	24,000 lb.	abt.28,000 lb	40,000 lb.	
63	Weight empty per square foot of heating surface	61.8	96.3	71.6	...	79.9	58.0	...	56.4	
	MISCELLANEOUS:									
64	Contents of coal tanks	...	...	...	...	1,700 lb.	...	2500 lb.		
65	Contents of water tanks	...	...	217 gals. Eng.	...	427 gals. Eng.	...	666 gals. Eng.		
66	Diameter of blast nozzle	3 in. (*x*)	2 3-8 in. (*x*)	1 7-8 in. (*y*)	3 in.	2 in.	...	2 1-2 in. to 3 in.	2 5-8 in.& 2 7-8 in.	
67	Maximum diameter of chimney	15 in.	11 in.	8 in.	44 in.	32 in.	32 in.	30 in.	66 in.	
68	Minimum " "	15 in.	11 in.	8 in.	16 in.	11 in.	11 1-4 in.	11 in.	15 in.	
69	Least sectional area of chimney in square inches	176.71	95.03	50.26	201.06	95.03	99.40	95.03	176.71	
70	Firegrate area divided by least sectional area of chimney	19.67	25.00	16.04	16.44	9.61	9.17	15.15	11.73	
71	Working pressure of steam in pounds per square inch	130 lb.	130 lb.	130 lb.	140 lb.	140 lb.	120 lb.	125 to 150 lb.	120 lb.	
72	Nature of fuel used	Anthracite	Anthracite	or Bit. coal	Anthracite	Bituminous	Bituminous	Bitum's (*z*)	Wood	
73	Tractive force for each pound of effective pressure per square inch on pistons	103.1	80.66	38.52	111.04	53.78	44	53.78	108.74	30.73
74	Tractive force with an effective pressure on the pistons equal to four-fifths the boiler pressure	10,722	8393.8	4006.1	12,436	6109.4	4224	6453	10,439	
75	Tractive force in previous line expressed in per cent. of adhesion weight	22.81	31.68	21.19	...	16.51	17.60	23.05	26.10	
	TENDER:									
76	Number of wheels in tender	8	8	...	8	...	8	...	8	
77	Diameter of " "	33 in.	24 in.	...	30 in.	...	26 in.	...	30 in.	
78	Material of " "	Chilled castiron	Chilled castiron	...	Chilled castiron	...	Chilled castiron	..	C. I. chilled tyres	
79	Contents of coal space	10,000 lb.	5500 lb.	...	7924 lb.	...	4000 lb.	...	Capacity1cd	
80	Contents of water tanks, Eng. gals.	2000	913	...	1833	...	1000	...	1666	
		23	24	25	26	27	28	29	30	31

NOTES REFERRING TO THE TABLE.

(*a*) In addition to the locomotives, particulars of which are tabulated here, there were a few others exhibited at the Centennial. The table, however, includes all shown within the building. Outside the Maryland State Building there were two engines, sent by the Baltimore and Ohio Railroad, one the No. 6 of that railway, the other No. 600. The former is one of a class built in 1835, and is with seven others still actively employed on shunting service. It was designed and built by Phineas Davis, of York, Pennsylvania, and has a vertical tubular boiler, fired from the front, through a projecting horizontal fire-box, and having two vertical cylinders attached to the rear of the boiler, one to each side. The piston rods of these cylinders are connected with vibrating beams above the top of the boiler, rods being connected to the ends of the beams, and giving motion to two wrought-iron cranks. This motion is transferred through spur gearing to the wheels, which are four in number, and 36 in. in diameter. The reversing gear consists of an ingenious arrangement of sliding cams worked by levers and by the foot. The weight of this machine is about 8 tons, and the working pressure 60 lbs. The whole of the work is remarkably good, and in this respect it forms a striking contrast to the new locomotive, No. 600, which forms a second engine exhibit of the Baltimore and Ohio Railroad. This is a heavy passenger engine of the "Mogul" class, and is built for working the traffic over the steep mountain sections of the railway. It weighs 90,400 lbs., and has six coupled wheels, with cast-iron centres and steel tires, 60 in. in diameter. The cylinders are 19 in. in diameter and 26 in. stroke, and the boiler is 50 in. in diameter. The fire-box is of steel.

(*b*) The only foreign engine exhibited. (Swedish.)

(*c*) This is a freight engine, but during the period of the Exhibition was used in working the traffic on the West End Passenger Railway.

(*d*) This engine is on the single boiler Fairlie system, with two four-wheeled bogies.

(*e*) Measure to centre of truck at forward end.

(*f*) The main wheels on the engines Nos. 14 to 21 have, as is common in our American practice, cast-iron centres and steel tires. The tires used are now almost exclusively of American make. They are shrunk on to the body, the amount of shrinkage being $\frac{1}{1000}$ in. per foot

of diameter of wheel. In some cases the tire is further secured by a number of set-screws passing through the rim of the wheel, and entering the tire. These screws are furnished with a nipple at the end about $\frac{5}{8}$ in. in diameter, and $\frac{3}{8}$ in. long, which fits in a corresponding hole in the tire.

(*g*) These wheels are of the Washburne pattern, of cast-iron, with steel tires. In making these wheels the latter are heated, and the bodies are cast within them. The tires are rolled with a bulge on the inside, so that the cast body cannot slip off. It is, moreover, claimed that a partial fusion takes place on the surfaces of contact between the iron and steel, making the whole wheel one solid mass.

(*h*) This dimension is the travel of the crank, the Walschaert's valve gear being employed.

(*i*) This dimension refers to the wagon top of the boiler.

(*j*) At front end of boiler.

(*k*) That there are two dimensions for the height of the fire-box is due to the fact that the grates are inclined, and sometimes the crowns also.

(*l*) The lesser of these dimensions refers to the back of the fire-box, and the greater to the front.

(*m*) Pennsylvania charcoal iron.

(*n*) Fastened with copper ferrules.

(*o*) Side sheets $\frac{1}{4}$ in. thick, back sheets $\frac{5}{16}$ in.

(*p*) The fire-box tube sheets in these two engines are $\frac{1}{2}$ in. thick.

(*q*) Crucible steel.

(*r*) Front tube plate $\frac{7}{16}$ in.

(*s*) Wagon top plate, $\frac{3}{8}$ in.

(*t*) In this fire-box there is a combustion chamber of 3 cubic fee. capacity.

(*u*) These blast nozzles are square. Engines Nos. 15, 16, 20, 21, have double nozzles.

(*v*) These nozzles are single.

(*w*) From $3\frac{3}{4}$ in. to $4\frac{3}{4}$ in.

(*x*) These nozzles are double.

(*y*) Single nozzle.

(*z*) Burned anthracite during its period of service at the Exhibition

(*aa*) Washburne wheels.

(*bb*) This engine and tender were built for exhibition by the appren-

tices in the Reading locomotive shop of the Philadelphia and Reading Railroad.

(*cc*) Counterweights are formed entirely in rims of driving wheels, dispensing with weights between spokes.

(*dd*) $\frac{1}{8}$ in. at front and $\frac{1}{16}$ in. at back.

(*ee*) At front.

(*ff*) Tube plate, $\frac{7}{16}$ in.

NOTE.—The Pennsylvania Railroad passenger engine (No. 15 in the table), and all the engines employed in working the traffic on the West End Passenger Railway at the Exhibition, were fitted with the Westinghouse automatic brake, and all the trains for the latter service are also fully equipped with this brake.

CHAPTER XI.

HIGH RAILWAY SPEEDS.*

RAILWAYS being now the common highways of our country, their managers naturally seek all means of accommodating and meeting the wants of the traveling community.

The active rivalry now existing between the Pennsylvania Railroad and the Bound Brook route of the Philadelphia and Reading Railroad has resulted in giving us the most improved facilities for communication between the two principal cities of this country, and has placed our railway speed on a par with the fast time of the British express trains.

It is but a few years ago that a trip to New York and back in the same day was considered a wonderful achievement; the time occupied, being three hours each way, was thought very short; whereas to-day one can have his breakfast and go to New York, transact business, and return and dine in his own house. But even the great reduction of time has not been considered sufficient to comply with the requests of rapid transit, and the two roads referred to are contemplating and preparing to run the ninety miles between Philadelphia and New York in ninety minutes.

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* W. Barnet Le Van.

Sixty miles an hour, as it strikes the ear, does not seem an impossibility; but if we look at it in all its bearings, and consider that it means *one mile in one minute*, or *sixty miles in sixty consecutive minutes*, it begins to assume proportions that seem insurmountable.

Some of the earliest locomotives ever built have run over a mile a minute, and in one instance a speed of ninety-three miles per hour was maintained for a few miles.

To illustrate more clearly the difficulties in running sixty miles in sixty minutes, the locomotive must be capable at all times of developing *seventy miles per hour*, so as to meet any contingency that may arise. A locomotive at seventy miles an hour passes over one hundred and two feet per second $\left(\frac{70\times 22}{15}=102.6\right)$. Two objects near a person, say three feet apart, pass his eye in the thirty-fifth part of a second. When two trains having this speed pass each other, the relative velocity will be two hundred and five feet per second; and if one of the trains were one hundred and two feet long, it would flash by in a single second. To accomplish this, supposing the driving wheels to be six and one-half feet in diameter, and the piston to change its direction in the cylinder ten times in a second, there being two cylinders to every locomotive, and the eccentrics being so adjusted that the exhaust steam discharges alternately, there are twenty discharges of steam per second, at equal intervals, and these twenty exhausts divide a second into twenty equal parts, each puff having a twentieth of a second between it and that

which precedes and follows it. The ear, like the eye, is limited in the rapidity of its sensations; and, sensitive as those organs are, they are not capable of distinguishing sounds which succeed each other at intervals as short as the twentieth part of a second.

Therefore, to run sixty miles in sixty minutes continuously and with a reasonable degree of safety, some modification in the form of engine as now built must be made. The road bed must also be in the best condition attainable, and as straight as possible, and if curves are indispensable they should not be less than two thousand feet radius.

Locomotives are distinguished as *single* or *coupled*, independently of their kind or class. When only a single pair of driving wheels is employed, the engine is said to be a single engine. When two or more pairs of driving wheels are used, connected by coupling rods, the engine is said to be coupled.

When six coupled wheels and a swing "pony truck" in front, connected by equalizing beams with the leading pair of coupled wheels, it is called *Mogul*, and when eight coupled wheels and "pony truck," it is called *Consolidation*.

To accomplish sixty miles in sixty minutes, the Baldwin Locomotive Works, of this city, have just placed on the Bound Brook route between this city and New York a new single engine, similar to those used on the fast lines in England, having but one pair of driving wheels, 6½ feet in diameter. The ordinary driving wheels of passenger engines in this country do

not exceed 5½ feet, and two pair coupled together are used. For fast speeds, with coupled driving wheels as in ordinary use, the momentum of the parallel rods which connect the driving wheels becomes enormous, and is a source of great danger. Within a month past the parallel rod of an engine on the Pennsylvania railroad broke. It demolished the cab of the engine, and seriously injured the engineer, and detained the train over one hour.

This new engine requires no parallel rods, and the increased diameter of the wheels also reduces the number of revolutions to the mile, as well as the centrifugal force.

In the ordinary locomotive with small and coupled driving wheels, the greatest speed of the piston reaches sometimes about 1,200 feet per minute with a two foot stroke and 5½ feet diameter driving wheels, giving about fifty-nine miles per hour; but with driving wheels 6½ feet diameter, and the same piston speed, the running rate would be about *sixty-nine miles* per hour. No more adhesion is required at high than at low speeds, assuming the load to be the same. The truth is, that the amount of adhesion required to turn to account the whole power which a locomotive is capable of developing varies inversely according to the speed at which the engine is run, the higher the speed the less being the adhesion required. The increased resistance, according to experiments made, is in a less ratio than that of the simple velocity, so that the boiler need not exceed the limit of space

afforded. The ordinary locomotive boilers do not exceed 1,100 feet of heating surface and 20 square feet of fire grate. In this new locomotive the boiler has about 1,400 square feet of heating surface and about 56 square feet grate surface.

The dimensions of the engine are as follows:

Cylinders, 18 × 24 inches.

Total wheel-base, 21 feet 1 inch.

From centre of driving to centre of trailing-wheels, 8 feet.

Boiler, made of steel, $\frac{7}{16}$ inch thick.

Diameter of boiler at smoke-box end, 52 inches.

198 tubes, 2 inches in diameter × 12 feet 2¾ inches long.

Fire-box, 96½ inches long × 84 inches wide, 51 inches deep in front, and 44 inches back.

Grates, made of water tubes, 1⅞ inches outside diameter × ¼ inch thick, spaced 2⅞ inches from centre to centre, with three bars arranged to pull out.

Truck has a swing bolster and four 36 inch-wheels, with cast-iron centres and steel tires.

Journals of truck axles, 5 × 8 inches.

Steam-ports, 1⅝ × 16 inches.

Exhaust-ports, 3 × 16 inches.

The valve is of the Allen pattern, with ⅞ inch lap.

Cross-heads are made of solid wrought-iron, with brass gibs on slides.

Driving-wheels, 6 feet 6 inches in diameter, with cast-iron centres, having solid spokes and hollow rim.

Tires 3 inches thick.

Driving-axles, made of wrought-iron, with journals $6 \times 9\frac{1}{2}$ inches.

Trailing wheels, 45 inches diameter, with cast-iron centre and steel tires.

Journals of trailing axle, $7\frac{1}{2} \times 8\frac{1}{2}$ inches.

Boiler supplied with two injectors. No pumps are used.

Tender carries 4,000 gallons of water.

Tender-frame made of channel iron.

Tender wheels 36 inches in diameter, with cast-iron centres and steel tires.

Tender axle journals, 5×8 in.

The weight of engine in working order is 85,000 lbs.

Weight on driving-wheels, from 35,000 to 45,000 lbs.

Weight on trailing-wheels from 15,000 to 25,000 lbs.

Weight on truck, 25,000 lbs.

The top and sides are stayed with $\frac{7}{8}$ in. stay-bolts. The boiler has 1,400 square feet of heating surface.

The Bound Brook road is not fitted with water troughs between the tracks, so that the locomotive tender can pick up its water while in motion: thus, larger tenders are needed to convey sufficient water for the through trip.

By dispensing with the coupling rods, and reducing the centrifugal force of the driving wheels, it is evident that the design of the engine is in the right direction for safety and fast running.

The tractive force of each pound of effective pressure per square inch on the pistons which this engine is capable of exerting will be

$$\frac{18^2 \times 24}{78} = 99.68 \text{ pounds.}$$

In running sixty miles per hour, on an ordinary road, which corresponds to about 258 revolutions, or a piston speed of 1,034 feet per minute, and a mean effective pressure of about 35 pounds per square inch, the tractive power exerted will be

$$\frac{18^2 \times 24 \times 35}{78} = 3,489 \text{ pounds}$$

for each piston, and the horse-power for the two cylinders will be

$$HP = \frac{18^2 \times 1,034 \times 35}{33,000} \times 2 = 552.72.$$

To run a train sixty miles in sixty minutes between Philadelphia and New York would not be considered as remarkable, provided the track was always clear; but several large towns, cities, and bridges, some of which have draws, are, however, scattered along the route, necessitating a material reduction of speed in passing them, and thus time is lost, which must be made up by a proportionate increase in speed on those parts of the roadway which are clear and unobstructed. This increased speed must be as great, at times, as *seventy miles* an hour, as before stated.

On Friday, May 14, 1880, I received an invitation from Messrs. Burnham, Parry, Williams & Co., to make a trip on a train to be drawn by their "new departure locomotive, No. 5,000," the 5,000th of their build (Philadelphia and Reading Railroad Company's No. 507), from Ninth and Green streets to Jersey City, over

the Bound Brook route, without stopping, and return in the same way.

As before stated, this locomotive has only one pair of driving wheels, 78 inches in diameter.

The weight is so disposed upon the wheels that by an alteration of fulcrum points operated by a separate steam cylinder, additional weight can be thrown on the drivers at the time of starting. This shifting of the weight will give from 8,000 to 9,000 pounds additional on the driving wheels.

The weight of the engine, ready for attaching to the train, is 85,000 pounds, and the tender 70,000. The train going to New York consisted of four day (set up) cars, of the usual pattern, each weighing about 42,000 pounds. Weight of train complete, about 148 tons.

THE START.

When the engine left the round-house, to take its place at the head of the train, I was reminded of what Elihu Burritt says, when writing about the locomotive:

"I love to see one of those huge creatures, with sinews of brass and muscles of iron, strut forth from his stable and salute the train of cars with a dozen sonorous puffs from his iron nostrils, then fall back gently into his harness.

"There he stands champering and foaming upon the iron track, his great heart a furnace of glowing coals, his lymphatic blood boiling within his veins; the strength of a thousand horses is nerving his sinews; he pants to be gone. He would drag St. Peter's across the Desert of Sahara, if he could be hitched on."

The signal to go ahead was given at precisely 11:16 a. m., and on account of Ninth street being more or less obstructed by teams crossing, 9½ minutes were consumed in reaching Wayne Station, distance 4.3 miles, rate of speed per hour, 27.15 miles.

Wayne Station to Jenkintown, distance 5.8 miles, time 6.75 minutes, rate of speed 51 miles per hour.

Jenkintown to Yardley, distance 20 miles, time 19 minutes, rate of speed 63 miles per hour.

Yardley to Trenton Junction, distance 2 miles, time 2¼ minutes, rate of speed 53.3 miles per hour.

Trenton Junction to Bound Brook, distance 27.1 miles, time 25¾ minutes, rate of speed 63 miles per hour.

Bound Brook to Elizabeth, distance 20.7 miles, time 20¾ minutes, rate of speed 60 miles per hour.

Elizabeth to Jersey City, distance 11½ miles, time 14 minutes, rate of speed 49.3 miles per hour.

Total time from Ninth and Green streets, Philadelphia, to Jersey City, 89.4 miles, 98 minutes, rate of speed 54.73 miles per hour.

THE RETURN.

On the return trip one car was added, making the total load 168 tons.

Left Jersey City at 2.07 Philadelphia time, reached Elizabeth at 2.21½, distance 11½ miles, time 14½ minutes, rate of speed 47½ miles per hour.

Elizabeth to Bound Brook, distance 20.7 miles, time 19 minutes, rate of speed 65.3 miles per hour.

Bound Brook to Trenton Junction, distance 27.1 miles, time 26.8 minutes, rate of speed 60.6 miles per hour.

Trenton Junction to Yardley, distance 2 miles, time 2⅓ minutes, rate of speed 53 miles per hour.

Yardley to Jenkintown, distance 20 miles, time 20.8 minutes, rate of speed 57.6 miles per hour.

Jenkintown to Wayne Junction, distance 5.8 miles, time 8 minutes, rate of speed 43.5 miles per hour.

Wayne Junction to Ninth and Green streets, distance 4.3 miles, time 8½ minutes, rate of speed 30.3 miles per hour.

Total time from Jersey City to Ninth and Green streets, Philadelphia, 100 minutes, distance 89.4 miles, rate of speed 53.6 miles per hour.

The best performance during the trip was in running the 2.8 miles from Willitt to Langhorne, part of which distance is an ascending grade of 16 feet per mile, in two minutes, being at the rate of *eighty-one miles per hour*.

A careful examination of all the bearings at the end of each trip showed them to be perfectly cool, which is something extraordinary for a new engine, running 90 miles without stopping.

To show the speed this engine is capable of performing, on a former trial she ran 13.8 miles in 10½ minutes, or at the rate of *seventy-eight and eighty-five hundreths* of a mile per hour.

Some idea of the steaming capacity of the boiler may be had from the fact that a No. 9 Sellers injector,

which will throw 2,000 gallons of water per hour, will not keep her supplied.

The water consumed in the 98 minutes' run to Jersey City was about 3,300 gallons, and on the return trip about 3,600 gallons, or about 34½ gallons, or 288 pounds per minute.

Comparing this time with the fast time made by the 7.35 a. m. going east, and the 3.30 p. m. coming west, on the Pennsylvania Railroad from Germantown Junction to Jersey City and return, we have as follows:

Pennsylvania Railroad.—Germantown Junction to Jersey City, distance 84.2 miles, time 106 minutes, rate of speed 47.7 miles per hour.

Reading Railroad.—Wayne Junction to Jersey City, distance 85.1 miles, time 88½ minutes, rate of speed 57.6 miles per hour.

Jersey City to Germantown Junction, distance 84.2 miles, time 103 minutes, rate of speed 49 miles per hour.

Jersey City to Wayne Junction, distance 85.1 miles, time 91½ minutes, rate of speed 55.7 miles per hour.

Being seventeen per cent. less time going east and twelve per cent. coming west than that now made by the Pennsylvania Railroad.

The advantage of large diameter for driving wheels is in the reduction of the number of revolutions per mile. In the Baldwin engine the revolutions per mile are $\frac{1680}{6.5}=258$, and those of the Pennsylvania Railroad, with a 5½ foot wheel, $\frac{1680}{5.5}=305$, an increase of

$\frac{305-258\times100}{305}=15.4$ per cent., and their engines being coupled, this additional number of revolutions adds to the risk by increasing the momentum of the parallel rods and tending to separate them.

It must not be supposed that 80 miles an hour is the limit of speed which a railway train may attain. Speed is a question of power and resistance, and velocities greater than 80 miles an hour, which is about 7,000 feet per minute, are in use in various kinds of machinery, to wit: fan-blowers, circular saws, etc.

The writer believes that before the expiration of five years, with the present active rivalry, passengers will be set down in New York in one hour's time from this city.

The mean average of all the English railways is 46.2 miles per hour; French, 37.5 miles per hour; German, 40 miles per hour; and American, 37 miles per hour; the English being 20 per cent. faster than in this country.

With them, 6½ foot driving wheels are quite as common as 5½ foot wheels are with us; in fact, some of the fast lines have eight and nine feet, and one line had ten feet diameter.

Engines with one pair of drivers are not new in this country. The *Ironsides*, built by M. W. Baldwin in 1832, had but one pair of drivers, 4½ feet in diameter. Mr. William Pettit ran her on the Philadelphia and Germantown Railroad at the rate of 62 miles per hour. Dr. Patterson, of the University of Virginia, and Mr. Franklin Peale, were on the engine, and timed its working on that occasion.

In 1849 Edward S. Norris, of Schenectady, built for the then Utica and Schenectady Railroad the *Lightning*, Crampton, with 16 inch cylinders, 22 inch stroke, and a single pair of 7 foot wheels, which ran at the rate of 60 miles an hour in the year 1850, but it only worked a short time.

Messrs. M. W. Baldwin & Co., in August, 1849, delivered to the Vermont Central Railroad an engine, the *Governor Paine*, with 17 inch cylinders, 20 inch stroke, and a pair of 6½ foot driving wheels, and subsequently sent three Crampton engines, of smaller dimensions, to the Pennsylvania Central Railroad in September, 1849.

Norris Brothers made seven engines for the Camden and Amboy Railroad, each with a single pair of 8 foot driving wheels, and a 6 wheeled truck. The first of these, with 13 inch cylinders and 34 inch stroke, was sent from the makers' shops, April 17, 1849. The next of the class had 13×38 inch cylinders, and were delivered December, 1849. The last of the series, delivered in April, 1853, had 14 inch cylinders and a 38 inch stroke. The 13 inch cylinders weighed, empty, 40,754 pounds, and loaded, 49,253 pounds. Of the weight loaded, 18,496 pounds, or about 8¼ tons, were on the driving wheels, with about 13¾ tons on the truck, making 22 tons in all. These engines had boilers 36 inches in diameter, with plates but $\frac{3}{16}$ inch thick.

In 1850 they also built two outside cylinder engines, with 14 inch cylinders, 32 inch stroke, and coupled 7

foot driving wheels, for the New York and Erie Railroad (new Erie Railway).

In the year 1849 Ross Winans, of Baltimore, built a single locomotive for the Boston and Worcester Railroad. It was for an experiment in coal-burning, and constructed to burn anthracite coal. This locomotive was named the *Carroll of Carrollton.* It had one pair of 7 foot driving wheels, and was intended for very high speed. It had two small steam cylinders placed on the sides of the boiler, over the bearings of the driving axle, by which the weight on the drivers could be varied from three to twelve tons.

The 7 foot drivers were cast with chilled rims and were of extremely light pattern; in fact they became broken after running six weeks. These were replaced with a set of imported wrought-iron wheels, the first of the kind brought to this country.

The speed of the engine, under favorable circumstances, was one mile in sixty seconds. It was run between Albany and Boston, and the train consisted of from seven to eight cars, and made a mile a minute with ease. The engineer, J. H. Jackman, says: "Since I run her in 1849, I have traveled many thousand miles on locomotives, and have seen some high speeds made, still I have never seen the locomotive that could lay right down to it and out-run the *Carroll of Carrollton.* When I run her we made many stops, and therefore could not make better time than locomotives having smaller driving wheels. But give me fifty or sixty miles on a clear run, and I could out-run a

thunder-storm if it was going our way. In those days we had no air-brakes, and to run at such high rates of speed sometimes became dangerous. I remember one instance, in the night time, of rounding a curve at about sixty miles per hour, when a danger signal met my view. I shut off steam and whistled down brakes, but they did not seem to check me. I whistled again; still the speed kept up. I gave the third signal for brakes, and then reversed my engine, saying to her, 'Do your duty, my beauty, or in twenty seconds it is good-by to railroading.' We came to a stand-still eighty rods from a train on the main track, having run one mile and a quarter from the place where I first discovered the red light. A locomotive engineer, to avoid trouble, must take time by the forelock—in other words, must anticipate possibilities."

Not over a dozen and a half of single engines have been made in the United States. Smaller wheels have been substituted for nearly all of these engines, from the fact that all the large-wheeled engines had small boilers, and with a single pair of driving wheels the adhesion was in all cases insufficient for the want of a proper distribution of the weight excess, as in the case of the *Carroll of Carrollton*, and, as before stated, the adhesion weight could be varied between three and twelve tons.

The present Baldwin has a similar arrangement, as before described, also the great advantage of a large boiler with ample heating and grate surface.

The Great Western Railway of England has seven

foot gauge, and was the fastest road in the world until a few years since, and its express ran regularly from Paddington (London) to Bristol. 118¼ miles, in precisely two hours, being at the rate of *fifty-nine miles* per hour.

CHAPTER XII.

RECENT IMPROVEMENTS IN THE LOCOMOTIVE.

THE last meeting of the Master Mechanics' Association was largely devoted to the consideration of the report of its Committee on the Construction of Locomotive Engines. The committee appointed to gather facts concerning improvements, or the remedy of well known defects in the construction of locomotives, report that in only two or three directions have valuable modifications been perfected. The committee turned its attention particularly to the consideration of questions relating to economy of fuel, locomotive trucks, spark-arresters or consumers, and the operation of consolidation locomotives. The committee report that they are in possession of no information that promises any real improvement in the form of construction of boilers, or in valves, or in machinery for working them.

In other respects, however, valuable improvements have been made, and chief among these is a spark-arrester, which, having been put to test by actual use, seems to have secured very important results. In the language of the report, it "has secured immunity from setting fires, not only arresting but perfectly consuming the sparks and smoke; also preventing the falling of fine dust from the train, improving the steaming

qualities of the engine, and resulting in the saving of fuel." The only ones described in the report are those in use on the Fitchburg Railroad, and on the Camden and Atlantic. Mr. Hill, the inventor of the one in use on the latter road, describes his invention as follows:

"A deflecting plate is arranged in the smoke-box near the flue-sheet, so as to cover the top flues, and extending downward toward the bottom of the smoke-box. A steel-wire netting is placed in front of said deflecting-plate to confine the circulating sparks from passing to the open air, or coming in contact with the exhaust steam. A straight pipe without any obstruction is used for a smoke-stack; the sparks after falling to the bottom of the smoke-box come in contact with an injector operated with a bell-crank and rod, under the control of the engineer. The power used to operate the injector is a small portion of exhaust steam, which can not be noticed by an expert. From the mouth of the injector a pipe is so arranged as to convey the sparks and steam to the fire-box. The moist steam used, being of a low temperature, readily combines with the smoke and gases, thereby supplying a deficiency needed to ignite them. Instead of admitting cold air into the furnace, warm, moist steam is admitted. The netting, to insure against clogging, is provided with a striker, under control of the fireman, and operated from the cab of the engine."

In regard to the operation of consolidation engines, the report presents an elaborate array of facts; although it acknowledges that they are not yet com-

plete enough to enable the committee to judge what the effect on cost of transportation will be. The committee, after making a comparison in points of expenditure for train hands, repairs, fuel, and interest on capital invested, between the 10-wheel and the consolidated locomotives, come to the conclusion that a given amount of work may be done by the latter, at a decidedly smaller cost than by the ordinary 10-wheel engines.

A large part of the report is devoted to the discussion of the best and most economical metal for locomotive and tender bearings; and here the practice seems to be quite varied. Nearly all builders use some combination of tin and copper; but while some mix the constituents so as to form a hard brass, others use it in the form of Babbitt metal. The committee, in summing up the evidence on this subject, express the belief that a majority of builders favor hard brass, composed of 6 parts copper to 1 part tin, for all axle and rod bearings. The use of Babbitt is not generally adopted for driving-axle bearings; but for truck and rod-bearings it is more often used than not, although it does not appear to give universal satisfaction. The important result seems to be recognized that Babbitt metal tends to lengthen the durability of the bearing, but to shorten that of the journal. It is generally understood that soft metal collects grit, and thus cuts away the journals, and the loss from this cause more than compensates for the saving in the wear of the bearings.

Another thing considered by this committee was the value of injectors; submitting a large number of facts, including a statistical table setting forth the observations with regard to the saving of fuel by the use of this appendage, furnished by Mr. E. T. Jeffrey, of the Illinois Central Railroad. The engine used by Mr. Jeffrey was run eight trips of 128 miles each, using her pumps exclusively, and then the same number of trips over the same section of road, using the injector exclusively. The engine burned 6342 pounds less of coal with the injector than with the pump; but nearly nine hours more time was spent in switching at way stations when the pump was used, which reduces the saving in coal to 4342 pounds. A chief objection to the use of the injector, as at present constructed, seems to be the difficulty in regulating so as to feed the proper quantity of water at all times. The committee consider that the following facts have been settled by the experiments which they have recorded:

1. A good injector properly attached is as reliable as a pump for feeding a locomotive boiler, provided the water in the tank is not heated to more than 110 degrees Fahrenheit.

2. A small saving in fuel is effected by using an injector; the boiler pressure is steadier, and the boiler is subjected to fewer changes of temperature.

3. A pump will feed only when the engine is moving, but an injector will feed the boiler when the engine is in motion, or at rest.

The report and the discussions thereon show that a

locomotive is probably, all things considered, the most perfect engine yet made by man. Certainly it is the one engine which has concentrated upon its construction the most thought and ingenuity.

CHAPTER XIII.

STRENGTH OF BOILERS.*

THE pressure in a steam boiler or other containing vessel tends to force the same into a circular form, if it does not possess that form; and if it does, the pressure has a tendency to sustain it in that form. Hence, the strongest form for a boiler is a circle, and any departure from that shape makes itself manifest by the necessity of stays. While the pressure acts from the center radially out to the circumference on an indefinite number of radial lines, the mathematics of the strength of the shell supposes that the pressure acts as

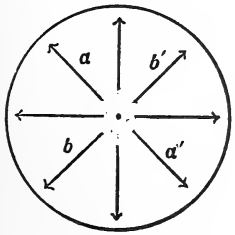


Fig. 32.

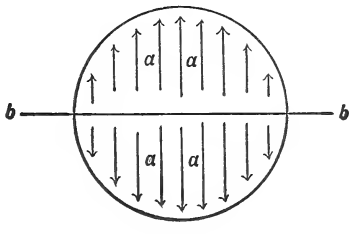


Fig. 33.

the arrows *a*, *a*, *a*, *a*, in Fig. 33, that is, tending to lift the top from the bottom. In Fig. 32 the pressure represented by arrow *a* is resisted by arrow *a'*, and similarly arrow *b* and *b'* resist each other, and as each

* Smith.

equals the other, we may assume any one direction as that in which the pressure acts, as *a*, *a*, *a*, *a*, in Fig. 33, tending to part the boiler through the line *b*, *b*. We might, as stated above, assume any other direction of the pressure, but as the shell is as strong through *b*, *b* as it is through any other similar section, the strength as ascertained at *b*, *b* will be the strength of the boiler. The standard of comparison between different brands of boiler iron is based on the strength of a *square* bar of that iron, the sides of which are one inch in length, and a section through the bar representing one *square* inch. The tensile strength of such a bar will average 50,000 pounds. Assuming, then, that the pressure tends to tear the top from the bottom of the shell, it is apparent that the force acting to do this is represented by the length of the shell in inches, multiplied by the diameter in inches, and by the pressure per square inch. The iron being the same thickness throughout the shell, we will also assume that a section one inch in length of the boiler is a *fac simile* as to strength of any other section of similar length. The iron being $\frac{5}{16}$ of an inch thick and one inch (assumed) in length, it is plain that its strength is but $\frac{5}{16}$ of our standard of comparison, 50,000 (or 15,625 pounds). Now, as we have *two* sides of the boiler of $\frac{5}{16}$ thick, we must double the above amount, which = 31,250 pounds as the strength of our section if it were without a joint. The strength of a single riveted seam (Fig. 34) has been ascertained to be but 56% of the solid iron, and hence we must take that percentage of 31,250 to arrive at

the strength of the weakest portion, which, of course, comes under the principle that the strength of any structure is equal only to its weakest part, 56 % of 31,250 = 17,500, which is the product of the length of our section (1 in) multiplied by the diameter, say 48 inches, multiplied by the pressure per square inch necessary to burst the boiler. We have, therefore, to find the pressure per square inch necessary to burst the boiler, only to divide 17,500 by the diameter (the length being 1 inch or unity). This gives us nearly 365ths, which, divided again by our factor of safety, we will take as 6 (or the working pressure = to $\frac{1}{6}$ the bursting pressure), and we obtain 60 nearly, as the proper working pressure, all of which tends to show that there are few locomotives in the United States that are not carrying more pressure than they ought to, or would be allowed to, if there was a law regulating the same.

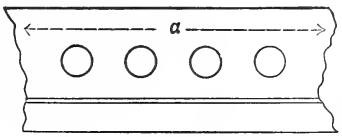


Fig. 34.

The strength of a joint, like Fig. 34, through the rivet holes, may be found by taking the length *a*, less the diameter of one hole multiplied by the number of holes. This leaves the length of solid iron between the holes, which, multiplied by the thickness and by the strength of a sectional inch, and from 15 % to 20 % deducted from the result, for injury done the iron by the punch, leaves the probable strength of metal between the holes. A staggered or double-riveted joint,

shown in Fig. 35, has 70 per cent. of the strength of the solid sheet, as ascertained by Fairbairn's experiments. From inspection, it will be seen that there is as much metal between the holes *h*, *c*, and *h*, *f*, as there is between *c*, *f*. The metal between the holes is much greater than in Fig. 34, while the number of rivets is in proportion to the metal left between the holes, and hence the strength of the joint may be deducted from the metal left between the holes on a line, *a*, *b*. The strength of a rivet, to resist shearing, is about 50,000 lbs. per square inch, hence the sectional area of one rivet, multiplied by the number of rivets, and again multiplied by 50,000, will closely approximate their shearing or detensive strength. The rivet area strength should be kept as nearly equal as possible to the strength of sheet between the holes. The strength of the sheet to resist crushing is represented by Fig. 36. It is plain that if the rivet does not shear, nor the sheet rupture between the holes, the part *a* must be pushed or sheared out of the way, if rupture takes place. The resistance which the part or piece, *a*, offers is represented by the area *b*, *b*, or the length *d*, by the thickness of the plate

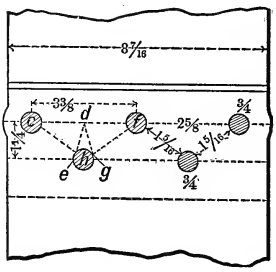


Fig. 35.

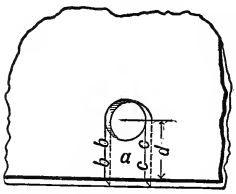


Fig. 36.

plus the equal area, *c*, *c*, and the whole multiplied by the detensive strength of the sheet, which is about 50,000 pounds per square inch. In designing a joint, the piece *a*, Fig. 36, the shearing strength of the rivets and the strength between the holes should be as nearly equal as possible, to make as strong a joint as is possible. The joint shown in Fig. 38 has a welt piece, *a*, added, and is much used in locomotive work. It does not add as much strength as is commonly accredited to it. The line of rivets *d* and *f*, Fig. 37, are commonly spaced twice as far as the middle one *e*, and therefore present only half the shearing strength of rivets that line *e* does, and hence if rupture were to take place it would occur first through either *d* or *f*, if it were not for the stronger joint *e*. Therefore, after the internal pressure exceeds the strength of joint *d* or *f*, they are no longer of use, as rupture is alone prevented by the superior strength of the joint *e*. The welt strengthens the joint, simply because it puts the rivet *g*, Fig. 38, into double shear, that is, the rivet must be sheared through the line *h* and *i*, and therefore presents double resistance. The part of the plate in front of the rivet

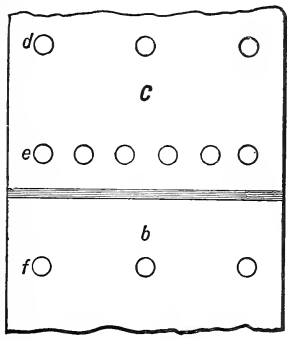


Fig. 37.

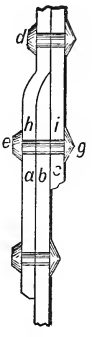


Fig. 38.

must be proportionally increased to meet the increased resistance, and the pitch of the holes increased as much as possible and still retain a tight joint. A combination of this joint and the staggered riveted joint would make the strongest possible longitudinal joint, as it would give the greatest amount of metal between the holes, and also present the rivet in double sheet. Fig. 39 shows a mode of making a joint by which the strength might be made equal to that of the solid sheet. The distance between the holes, by

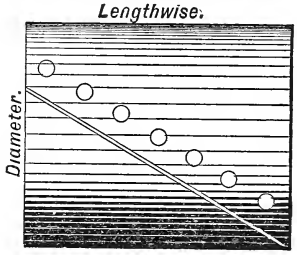


Fig. 39.

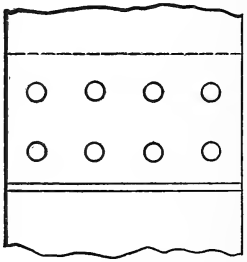


Fig. 40.

making the joint long enough, might be made equal to the width of the sheet, or in excess of it, for injury done in punching. The joint shown in Fig. 40 is not strengthened by the second row of rivets, barring the grip due to contraction of the extra rivets, as the strength of metal between either row is the same, as is also the number of rivets, etc.; and the joint is as weak through one row of rivets as the other. I have been considering the longitudinal strength only. The transverse strength of a boiler is that which prevents one end from being torn from the other. This

strength is represented by the thickness of the iron × by the circumference × by the strength of a sectional inch, and the whole less the percentage of loss due to the kind of joint. However, a single rivet joint will suffice, generally, as the boiler is about twice as strong transversely as longitudinally.

Persons buying boilers would do well to have samples of the iron, from which the boiler is to be built, tested for tensile strength, and take no interested parties' word, or bond, either, on that point. An actual test settles the matter beyond doubt. All holes should be drilled and rounded in the inner edge, as shown at *a*, *a*, *a*, *a*, Fig. 41, as a drilled hole, if not rounded, will shear the rivet sooner than a punched hole. Flat surfaces should be stayed to from six to ten times the pressure they are to resist. The *area* of rivets holding crow feet to boiler heads, etc., should be equal to the stay coupled to said crow foot. It is a good plan to make stays coupled to crow feet slightly shorter than the required length. Expand them by heat, and, on cooling, they will all be found tight and necessarily bearing their proportional strain.

Fig. 41.

It is a *bad* plan to collect one end of stays (such as crown sheet stays when stayed to shell) into a smaller area than the other, as it is plain to be seen that the smaller area must resist more than its share in proportion as its area is smaller.

BOILER PROPORTION AND CONSTRUCTION—RIVETING AND STAYING.*

It has been determined by many experiments that the use of steel rivets increases the cost of construction, by reason principally of the loss by overheating and burning, while in hammering they often chill so rapidly that the heads are easily knocked off; this trouble showing itself even when mild steel is used. A steel rivet should only be used where the system of machine riveting is on the hydraulic plan.

Machine processes in all cases close the joints and fill the holes better than hand riveting, as the whole body of the rivet is reached by the pressure of the machine, but I believe that in every kind of machine riveting, pressure rings surrounding the rivet on both sides of the plates should be used to assist in bringing the joint home and to prevent the sheets from being separated by the squeezing of the rivet while very hot, in a transverse direction under or between the sheets, though in hydraulic riveting the pressure is so gradual that the partial cooling of the rivet prevents it from "bulging" and separating the joints.

In drilling or reaming plates it is easy to slightly round the corners of holes on both sides of the sheets, thereby reducing the tendency to shear all of twenty per cent., and punched holes should have the corners reamed in like manner.

There is one point in the construction of a boiler that often receives very slight attention, viz.: the form-

* Hoffman.

ing or forging, and fastening of crow feet or stay lugs to shell and heads. It is not a rare thing to find crow feet forged of flat bar iron strong enough to resist with perfect safety a working strain of 40,000 lbs. fastened to the shell of a boiler with two 5/8" rivets, and these receiving the stress at an angle of 45°.

I think that a neat and strong crow foot can be dropped or rolled with two, three and even four webs to receive rivets; these can be heated and bent to any form desired. This method would certainly establish a uniform standard as to strength, and would materially reduce the cost of manufacture in the shop, besides the advantage in having room for extra rivets.

The stays should be of the best material hammered from the merchant bar. Holes in the ends rimmed to size. The stay pins should be turned and drilled to receive annealed wire guard pins. Where threads are used the parting of rod on which thread is cut should be enlarged, so that the bottom of thread will have the same sectional area as the body of stay rod. Continuous head stays should have steel expansion collars to allow for expansion of tubes. Collars must be of steel. Every stay rod should be so arranged that it can be removed from the boiler and examined and tested, and wherever pitting and wasting are discovered the stay should be condemned, and a perfect one inserted.

Careful experiments with locomotives have proved that a brick arch in the fire box, as well as a baffle plate within the smoke box, are both very economical appliances. They save coal and prevent throwing fire. It

has also been found by experiment upon one of our leading railroads, that 54 per cent. of the heat produced by combustion, is put directly into the boiler and can be accounted for.

HOLDING POWER OF TUBES IN STEAM BOILERS.

The *Locomotive* for May, 1881, gives the results of some experiments made by the Hartford Boiler Insurance Company in their own work, with boiler tubes set in different ways, which reveal facts of special interest to boiler makers and steam users.

It has been claimed that by simply rolling in the tube with a Dudgeon tube expander, little holding power was secured. As this apparatus is so generally used by boiler makers, it seemed important that some experiments should be made to determine what would be the holding power of a tube rolled in by this apparatus. Arrangements were therefore made with H. B. Beach & Son, boiler makers in Hartford, to prepare for the insurance company three specimens composed of tubes three inches external diameter rolled into ⅜ inch plate in the ordinary way, without any expanding other than that produced by the apparatus.

Mr. Allen treats the subject as follows:

"So much depends upon the proper use of the Dudgeon Expander that some mechanical engineers are quite reluctant to accept the theory that all tubes thus rolled in, are equally effective in sustaining the head, or tube sheet. This criticism is in a measure true, and hence all boiler makers who have pride in their work and regard for their reputation, should know that this

work is well done. The riveting over of the ends of the tubes is quite generally practiced, and when well done makes a very strong joint, but those who are familiar with this kind of work know that in many cases the ends of the tubes are frayed out and split, and until the 'thumb tool' is brought to bear, the job has a very unpromising look. Such work yields readily to the action of the heated gases, and after a time the riveting, or beading, fractures and crumbles off, and very little strength remains. This fraying and cracking is sometimes attributed to a want of proper annealing of the ends of the tubes, but it is quite as often the result of unskilled workmanship. We have seen it so often that we are never sure that it is well done."

"Another method of fastening tubes into the tube sheet, and one that, so far as we have investigated, works well, the test being upon boilers in use, is to adjust the tubes so that they shall project slightly beyond the tube sheet. Roll them in with the Dudgeon Expander, and then, with one of the tools shown in Figs. 42 and 43, flare, or further expand the projecting ends. Figs. 44 and 45 show the above tools in cross section."

"Little explanation of the manner of using them is necessary. After the tubes are rolled in, either of the above tools can be used for expanding the ends. Some prefer the tool with two points of contact, and others use the one with three. The tool is inserted into the end of the tube and driven with a hammer until the

end of the tube is brought solid against the tube sheet. Only light blows are required, and the workman can

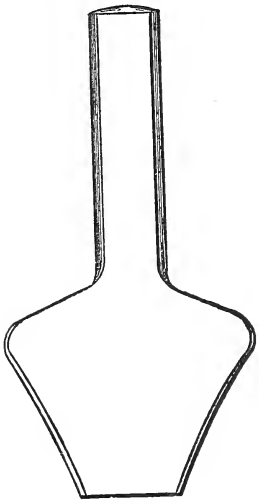


Fig. 42.

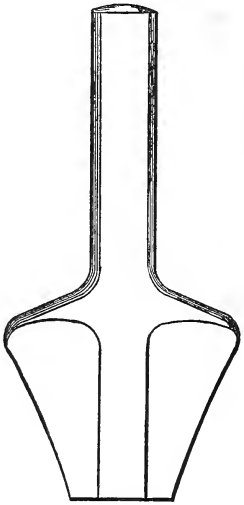


Fig. 43.

readily tell when the expanding is sufficiently done. Fig. 46 shows a tube which has been expanded by this method.

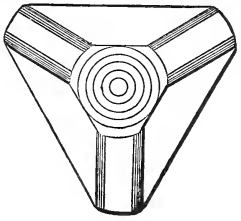


Fig. 44.

Fig. 45.

"In order to ascertain what the holding power of tubes set in this manner would be, we arranged with H. B. Beach & Sons, boiler makers of this city, to prepare for us two (2) specimens for test. They were tubes three inches external diameter rolled into 3/8 inch plate, and expanded as described above. These specimens were handed to Mr. Charles B. Richards, Consulting Engineer at Colt's Armory, in this city, with the request that he submit them to the required test. The following is Mr. Richards' report:

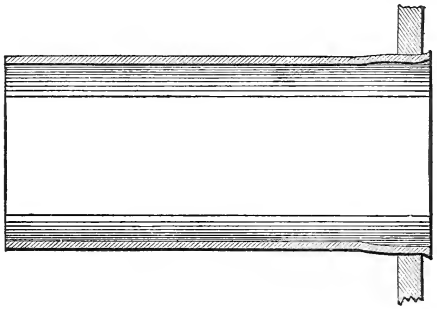


Fig. 46.

"'*Report by the Colt's Patent Fire Arms Manufacturing Company, of tests of the holding strength of two boiler tubes expanded into iron plates. The samples were received October 8th, from Mr. J. M. Allen, and were tested for him.*

"'The external diameter of the body of the tube was 3 inches, and the thickness 0.109 of an inch. One end of the tube was fastened in an iron plate $\frac{3}{8}$ of an inch thick and 6 inches square. The tube was fastened

in the plate by being expanded, and the end of the tube, which projected $\frac{3}{16}$ of an inch beyond the plate, was flared so that the external diameter of the extreme end was 3.2 inches, while the diameter of the tube where it entered the plate was expanded to 3.1 inches in diameter.

"'The test was made by observing the stress required to draw the tube out of the plate, but the tube was not wholly removed from the plate in specimen No. 1,079.

"'Both samples were originally alike, so that the description of one of them answers for both.

"'The stress which was sustained without the tube yielding in the plate was

For specimen 1,078, 20,000 lbs.
For specimen 1,079, 18,500 "

"'The observed stress which first produced yielding was

For 1,078, 20,500 lbs.
For 1,079, 19,000 "

"'And the observed stress which occasioned failure was

For 1,078, 21,000 lbs.
For 1,079, 19,500 "

"'The force was applied parallel to the axis of the tube, and the plate surfaces were held in planes at a right angle to the tube axis.

"'C. B. RICHARDS, *Engineer.*

"' *Office of Colt's Patent Fire Arms Manufacturing Co., Hartford, October 9, 1880.*'

"From the foregoing, it will be seen that the ob-

served stress which first produced yielding was 20,500 lbs. and 19,000 lbs. To ascertain what the holding power of the tubes in an ordinary tubular boiler 48″ in diameter would be, we have to multiply the holding power of one tube by the number of tubes.

"Fig. 47 represents the tube head of a 48″ boiler.

"We will assume the lowest result of the experiments, viz., 19,000 lbs., as the holding power of one tube. In the above tube head there are 47 tubes, and 47× 19,000=893,000 lbs., the holding power of all the tubes. It will be seen that these tubes are in the lower half of the boiler. The upper half is supposed to be thoroughly braced and stayed by stay-rods running back on the body sheets of the boiler. Consequently the tubes furnish the support for the lower half of the tube head. (We are not now taking into account the support derived from the joining of the flange of the head to the body of the boiler.) To ascertain the actual resistance of internal steam pressure to be overcome and provided for, we first ascertain the area of the head in inches, and multiply it by the internal pressure per square inch. The area in square inches in a tube head 48 inches in diameter is 1,809.6 square inches. But we have already stated that the upper half is supported by braces and stays running back on to the body sheets of the

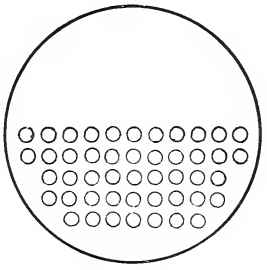


Fig. 47.

boilers, therefore only half the head is dependent upon the tubes for support, 1,809.6÷2=904.8 square inches. Again we find that the lower half of the head is largely taken up by the tubes, consequently the area upon which the internal pressure can act must be further reduced by the area of the tubes. The area of a 3-inch tube is 7.069 square inches, which multiplied by 47=332.243 square inches; 904.8—332.243=572.557 square inches, the area of lower half of head upon which the internal pressure would act. We will assume the internal pressure to be 80 lbs. to the square inch, then 572.557×80=45,804.56 lbs., to sustain which we have the holding power of the tubes, 893,000 lbs., or nearly twenty (20) times the internal pressure on the lower half of the tube head. This, it must be understood, does not take into account the fact that the tube head is firmly secured to the body sheets of the boiler by its flange besides. As we have already said, boilers with tubes set in this way have been under our care for some years, and we have seen nothing to lead us to apprehend any trouble. The ends have given little or no trouble by being subjected to the heated gases. We would not recommend a projection of the tube beyond the tube sheet of more than one-eighth of an inch before expanding."

THE FAULTY CONSTRUCTION OF LOCOMOTIVE BOILERS.*

We will first consider the manner in which the dome is attached to the shell of the boiler, which is usually done by locating it, and cutting out the hole

* Lyne.

by punching a row of holes close together (Fig. 49), completely around the piece to be taken out; the bottom edge of the dome is then flanged to fit the top of the boiler. Now, unless the iron is of the best quality, and the workman well skilled, there is great danger of the flange cracking, and in time the chemical action of the steam and water will cause a serious leak on the sides where the flange fits upon the shell of the boiler.

We remember seeing several cases where this took place, and particularly one, where there was a crack of nearly six inches in length; the only remedy then being to put on a patch over it, thus impairing the strength and looks of the boiler. A better plan is the following: By referring to Fig. 48, the reader will readily understand the principle, and it will be observed that the sheet forming the shell of the boiler is also flanged as well as the dome, thereby adding greatly to the strength. We remember one man who was so much absorbed in this plan that he claimed to restore the shell of the boiler to its former strength, by applying the dome in the manner shown in the cut. We believe this to be an exaggeration; but, however, we get a good strong job, and a durable one. It is the practice in some parts of Europe to put a stout wrought-iron ring round the hole under the base of the dome. Now, while we admit that there are other means of fastening the dome to the shell of the

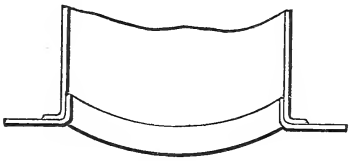


FIG. 48.

boiler, and some of them good, no doubt, we will say that we never saw the least trouble from a boiler with the dome attached represented in Fig. 48, therefore we consider it the best. Another important consideration is, that by flanging the shell of the boiler, the hole through it is left as large as the inside diameter of the dome, and no ragged edges left by punching out the piece as represented by Fig. 48.

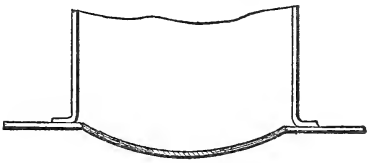


FIG. 49.

The question will, no doubt, be asked by the inquisitive, What harm do the ragged edges do? Well, we will answer for the benefit of the uninformed: Every man who has had any work to do inside of a boiler of this style, knows to his sorrow, and from the torn clothes and bruises caused by these sharp edges. It is a very easy matter for the draughtsman to sit in his office and design a boiler, and when placed in glowing colors on the paper it appears very nice; but during all his work he does not consider whether his designs will work in practice. When all the work is new, there is very little difficulty in putting the different parts together; but a very essential point is, that the parts should be made easy of access, and so designed that they may be taken apart with as little cost as possible. There is an old railroad principle of economy expressed very truly in this sentiment, that they "*in their efforts literally fall over a locomotive to pick up a spike.*"

We remember seeing two men work two or three days in getting out the steam-pipes, and finally broke off the flange, and spoilt the section so that it had to be replaced by a new one. If the designs had been properly made there would have been no trouble, and the work done in half a day or less.

So much for the application of the dome. We will now consider the manner of applying braces to the dome by a reference to Fig. 50, where A represents a

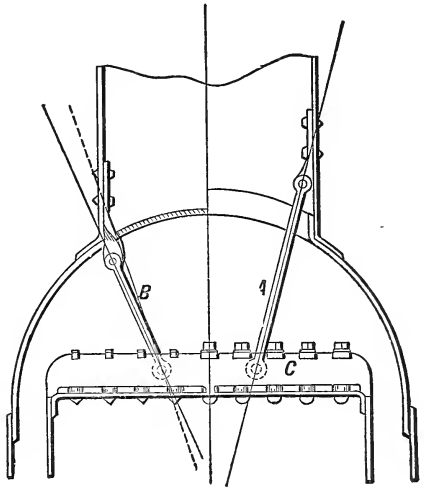


FIG. 50.

brace properly applied, and B represents a fault very common where too many privileges are allowed to the workmen.

We have had occasion several times in our exper-

ience to replace nearly all braces in the dome in consequence of this carelessness.

Any good mechanic knows that these braces are attached to the crown-bar, C, and the dome, to strengthen those parts, and therefore it is absolutely necessary that the braces be put in so as to take the strain at once.

If the reader will look at the cut he will see that the brace B is little or no support to the boiler in its present condition.

When the strain is brought to bear upon the brace, it will straighten out the clip which is riveted fast to the dome, until the center line of the brace corresponds with the dotted line, that being the direct line of strain. Braces put up in this way are very deceptive, and require close inspection to discover these faults; for when struck with a hammer, they will appear to be tight, and the only way of detecting them is by the eye.

It is a common practice among builders of locomotive boilers to make these braces all in one piece. that is, instead of the clip, they simply weld a piece of flat iron to the end of the brace, drill it, and rivet it fast to the dome.

Braces put up in this manner cannot be taken down without cutting out two rivets; and then, again, in putting up, if they are not exactly of the right length they will be very troublesome.

The advantage of the style of brace shown by A in the cut, at once commends itself to the observer. It

is not only better for adjusting them, but they may be removed altogether and repaired, or, as is often necessary, several may be removed in order to work about them.

Another very bad practice is in marking these braces with a cold chisel, for by this process the skin of the iron is broken, and we have seen one case where the iron was corroded away until the brace was only about one-quarter inch in diameter. This action was started by a mark made with a cold chisel. The workman, in putting up these braces, should be particularly careful in fitting the clips so as to be supported in the direct line of strain (indicated by the dotted line), so that there may be no straightening process before the brace is any support to the boiler. This explanation will be made plain by referring to the cut.

Now a few words in reference to the application of crown-bars, which are the braces that support the crown-sheet on top of the fire-box, as represented by C in Fig. 50. These bars are usually formed of two bars of flat iron ¾ in. by 4 inches, welded at the ends, or fastened together by rivets. They are placed across ¾ in. above the sheet, each end having a lip turned down and resting upon the top edge of the side sheets. The bars are placed about 5 inches apart, from center to center of the bolts by which they are fastened to the crown-sheet. These bolts are usually made with a T head which hooks over the top of the crown-bars, and is riveted on the underside of the crown-sheet. Each crown-bar has two braces to the shell of the boiler,

generally bolted to crow-feet. The most trouble that we have experienced in connection with the crown-bars has been from the leak around the bolts or stripping entirely. Such a bolt is represented in Fig. 51, where the bolt is simply riveted on the under side of the crown-sheet (there were no threads on these bolts), and frequently in riveting the heads become fractured, consequently when the strain comes upon them they snap off, thereby causing great trouble. Another plan used by some builders is represented by Fig. 52, where the hole in the crown-sheet is tapped and the bolt is screwed down from the top, with a nut placed upon the end that projects through the crown-sheet. It is a very easy matter to put these bolts in when the boiler is building, but when the boiler has been running awhile, and it becomes necessary to replace any of these bolts, it is quite a difficult operation. It is a difficult task to operate a wrench inside of the boiler, and we have, time and again, heard men (as the boys say) swear a page or two by note, and pronounce all sorts of imprecations upon the designer, while replacing some of these bolts.

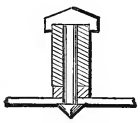


FIG. 51.

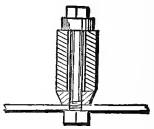


FIG. 52.

The nuts upon the end are very good if proper care was observed in screwing them up, but in our experience we have found that the nuts may be screwed up tight when cold, and yet when steam is raised upon the boiler these nuts will be found to move quite

easily, owing to the fact that the bolt is elongated by expansion.

We have not space to describe the many ways of fastening crown-bars: as a matter of course some of them are good and some worthless. But we will describe a plan which we have thoroughly tested for a number of years, and is now in use, believing it to be the cheapest, and we will also say the best way of applying crown-bar bolts.

By an inspection of Fig. 53, the reader will observe that we have a plan differing from those previously described. We have a die to fit the bolt-machine or swage-block, with a hole through it to admit ⅞ in. round iron. The top of this die is bored, tapering to the depth of 1 inch, and reamed with a taper reamer (shown by Fig. 54), with the collar A removed, making the hole 1⅛ in. diameter at the top, thereby giving a taper of ¼ in. to 1 in. of length. The bolts must be heated as nearly as possible to the same degree, then placed in the die and the round head of 1½ in. diameter formed. The threads are to be cut in a bolt-cutter, which is all that is required to finish them. To prepare the crown-sheet for their insertion, we place the collar A, Fig. 54, upon the reamer, and ream one of the holes previously punched with a ⅞ in.

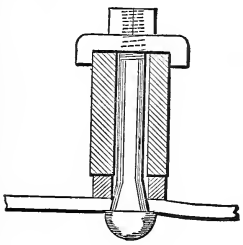


FIG. 53.

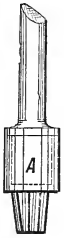


FIG. 54

punch, and allow the bolt to go up to within 1/8 in. of the head. The object of the collar A is to act as a gauge, running the reamer down until the face of this collar touches the sheet. This collar is faced off and properly gauged at the time it is made, and there are four grooves filed across the face to clear away the chips which would otherwise lodge under it while running.

It will readily be seen that by this process we get the holes of a uniform size. If the reader will look at Fig. 53, we will describe the application. It will be observed that there is a collar of 3/4 in. thick between the bars and the sheet, while a piece of flat iron with the ends turned down so as to form a lip is placed across the top.

When the bolt is put in place, and the nut tightened, a few smart blows with a heavy hammer will bring it up to the head. We remark here that the ends of the bolts inside of the boiler should never be allowed to project through the nuts, as the threads will become corroded, and when the attempt is made to unscrew them they will invariably be broken.

The same rule holds good for all bolts inside of the boiler and smoke-arch. This method of applying crown-bar bolts possesses several important advantages, as follows: By using the rough iron bolt, the skin of the iron not being broken, they possess superior strength, and using the taper, the strain is taken off the head. They are easily removed, and we never knew one to break; therefore, for cheapness and dura-

bility, we think this plan cannot be excelled. We would add a few remarks in regard to the management of boilers.

Whenever there is a boiler explosion, there is no end to the people expressing their surprise at the catastrophe, but it is equally surprising to us that there are not more explosions from the careless manner in which steam-boilers are handled. We were shown a boiler a few days since, and were informed that it had run between three and four years without being washed out, and that there was a cart-load of dirt taken from it. No doubt that there were any amount of complaints about that engine consuming so much coal with so little effect.

We advocate the plan of leaving out the three lowest rows of tubes, considering them of no use, as they are nearly always stopped up, and in their stead place a good-sized hand hole in the front end, whereby a scraper can be inserted and the dirt loosened; then, with a hose, wash it out. If neglected, the space left by the removal of the tubes leaves so much more space to fill up with mud before it will interfere with the heating surface.

A common practice among engineers is to pull down the lever of the safety-valve, or screw down the pop-valve, if it is a possible thing, until the gauge shows 130 lbs. per square inch, the limit of pressure allowed to be carried on the majority of roads. We remember a case where a certain engineer made a brag of how much work he could do with 80 lbs. of

steam, and finally the gauge on his engine was taken off and tested, and it was found that he had been carrying 140 lbs. per square inch. It is our opinion that a steel spring such as are used in steam gauges and on safety-valves cannot be trusted; and in view of this fact, no gauge should be allowed to run over three months without testing. It is a small operation, and pays well in the end.

In firing up a boiler when cold, the fire should be started very slow, and allow the iron sufficient time to heat uniformly. Many a boiler has been ruined through allowing some ignorant person to fire up under it.

CHAPTER XIV.

SLIDE VALVES.

This is a branch of the subject deserving the special attention of the engineer. Its importance in regard to the economical working of the steam engine cannot be overestimated.

The slide valve ordinarily used in locomotive engines, and the manner of its operation, is well known to nearly every practical mechanic and engineer. It will be remembered that the operations of admitting the fresh steam and releasing the waste steam are alternately performed by the same valve and the same motion. The valve being made to slide backwards and forwards upon the face of the ports, opens and closes the several passages in their turn. The two extreme ones, called the steam ports, communicate with each end of the cylinder. The middle one is called the exhaust port, and its corresponding passage terminates in a pipe open to the atmosphere. Steam is admitted freely into the steam chest from the boiler, and the valve is made of sufficient length to cover all the ports, when it is placed in the centre of the stroke. When it is in this position no steam can enter the cylinder, but as the valve moves on one of the ports opens, the arrangement of the valve gearing being

such, that when the piston is ready to begin its stroke, the steam port begins to open. During the stroke of the piston, the valve not only travels to the end of its stroke, but also returns to the point from whence it set out, and its continued motion in the same direction finally closes the valve and prevents any further admission of steam. The steam has now done its work, and must be removed. In the middle of the valve a hollow chamber is formed, of sufficient length to open between the ports. As soon as the edge of this chamber passes the edge of the steam port, the pent up steam finds vent and rushes through the exhaust port and escapes through the exhaust pipe into the atmosphere. Now looking at Fig. 55 you will notice

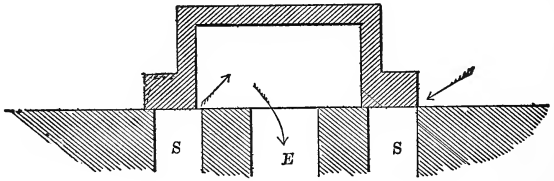


FIG. 55.

that the exhaust port opens when the steam port closes, and that both happen just at the end of the stroke. The perfection of a steam valve, other things being equal, consists in the degree of nicety with which its motion is timed relatively to the motion of the piston. The functions of the piston are absolutely dependent upon the proper timing of the admission and release of the steam. A very slight and apparently trifling error in the adjustment produces a most

serious effect upon the consumption of fuel. If from any cause the valve should open to admit steam for a fresh stroke before the preceding stroke is finished, it opens too soon, and an unnecessary resistance to the piston is produced. If, on the other hand, the valve should delay its opening until the piston had begun its return, it opens too late, because then the steam has to fill uselessly the space left vacant, and hence a waste of steam and loss of power. As far then as the admission of steam is concerned, it is a necessary condition that the *steam* ports should open neither before nor after, but at the precise moment when the stroke commences. Some engineers recommend giving the valve "lead" as it is termed, that is to say, setting it so as to open a little before the end of the stroke, but it is an open question whether the slightest advantage is gained by so doing to a greater extent than is necessary to compensate for any slackness or lost motion in the valve gearing or for their expansion when heated by the steam, and $\frac{1}{16}$ of an inch is quite sufficient in a well-constructed engine. It is also an open question whether it would not be better to bring the piston to a state of rest by the "compression" of the exhaust steam than by means of any lead to the steam valve at all. Now the valve shown in Fig. 55 satifies the conditions for the *admission* of the steam; it opens exactly at the right time; the steam begins to enter as the piston begins to move, as it follows it steadily and effectively throughout the stroke. Whatever *time* the piston takes for its journey, the steam is

allowed as much time to follow it. At first the opening is small, but then the motion of the piston is comparatively slow and therefore the supply keeps pace with the demand.

As respects the *release* of the steam when the stroke has been completed, the performance of this valve is altogether unsatisfactory, and here lurks the cause of the difference in the performance of the old and later engines.

But it may be said that the release does appear to take place at the right time, because it occurs just when the piston has finished its stroke, and if it were to occur before, a loss of power would ensue. This is a very plausible view of the case, and the one which delayed for years the saving of fuel which has since been effected. Sufficient attention was not bestowed upon what was going on in the cylinder, or upon the facts which might have indicated them; to fill and empty a cylinder full of steam are operations requiring *time*. The time required for filling the cylinder with steam necessarily corresponds with the duration of the stroke, whatever its duration may be. But this cannot be the case as regards the second operation—the emptying of the cylinder. This ought to be performed in an *instant*, or otherwise the steam continues pent up when it ought to be liberated, when it ought to assume its minimum pressure—the pressure of the atmosphere—and exerts an injurious counter-pressure against the piston, tending to increase the resistance to be overcome. To effect the free and rapid dis-

charge, it is necessary not merely to open the communication to the exhaust pipe, but to open a wide passage, and to have this done by the time the piston commences the return stroke. The valve alluded to cannot accomplish this, its motion being gradual, not instantaneous, as it should be. The passage only begins to open when the piston is in its turn, and it is not wide open until the piston has travelled through one-tenth of its entire stroke. The steam in the cylinder is restrained from escaping, being, as it were, wire-drawn in the passage out, and consequently takes considerable time to assume the pressure of the atmosphere. In the meanwhile the new stroke has begun and been partly completed, and so far the piston has had to contend with a resistance altogether illegitimate, a resistance in many cases—especially at high speeds—nearly equal to all the other resistances put together. It was not until the year 1838 that the true cause of the trouble was suspected and a remedy applied. It had been thought, before that time, that giving an engine lead tended to improve its speed when already running at a high rate. This was attributed to the opening of the steam port being wide at the commencement of the stroke, thereby increasing the facility for the entrance of the steam in following up the piston. Its true explanation was found to be the *earlier release of the waste steam* and consequent diminution of resistance. As sometimes three-eighths of an inch, or even one-half of an inch, "lead" was given in high-speed engines, it was decided to try the

effect of opening the exhaust passage earlier by the same amount, while the steam port should still be made to open only at the beginning of the stroke. An engine was chosen for the experiment, the valve of which resembled Fig. 56, placing the valve on the ports so as to allow the exhaust passage to be three-eighths of an inch open, the steam port at the same time to be one-quarter of an inch open. This space, therefore, was closed by adding to the length of the valve at each end one-quarter of an inch. The eccentric was, of course, shifted on the shaft to correspond with the alteration, and the engine with the altered valve (see Fig. 56) again set to work. It is almost

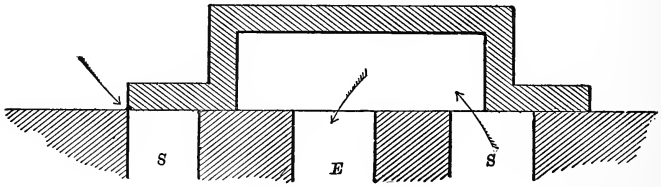


FIG. 56.

needless to say the saving of fuel was very great. The amount by which the valve at each end overlaps the steam ports (see Fig. 56) when placed exactly over them is technically termed the "lap." The lap of the valve being three-eighths of an inch, the exhaust passage was about three-eighths of an inch open when the stroke was finished.

LAP.

The importance of putting lap upon a slide valve

will be better understood by noting what would happen without it. If there were no lap the opening for steam would be represented by O D (see Fig. 57), and the

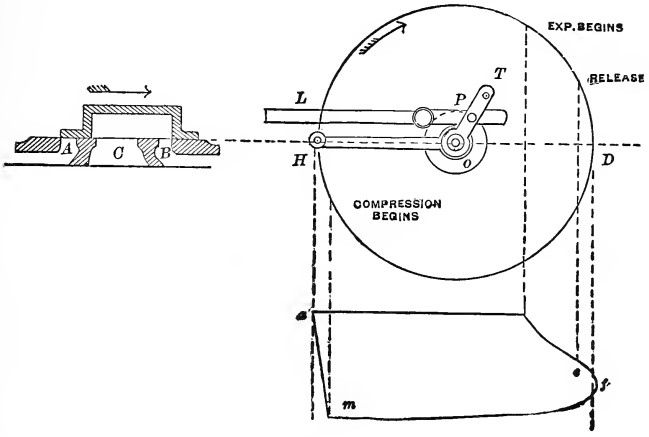


FIG. 57.

result would be that the steam port could only be perfectly closed at the precise instant when the valve was in the middle of its stroke and moving most rapidly. From what has been said it is apparent that a valve of this kind (one without lap) is unsuitable for an engine, the better plan being that the steam should be compressed or cushioned on one side of the piston, so as to assist in bringing it to a state of rest, and that the driving pressure on the opposite side should be relieved by opening a passage to the exhaust or releasing the steam just before the stroke terminates. This prevents the violent jerk and strain which would come

upon the crank-pin if the steam were thrown with full force upon the piston when the crank is on the center.

The value of an indicator diagram in interpreting the action of a slide valve can now be made clear. Referring to Fig. 57, it will be noticed that the moving parts are attached to a board carrying a sheet of paper on which the circles describing the centres of the crank-pin and centre of eccentric are recorded: and below this is a space for tracing the indicator diagram. The crank and connecting-rod which actuate the piston are at the back of the board, but an index arm, O H, is placed in front and moves with the crank, thereby transferring its apparent motion to the part where it can be seen. The eccentric is represented by an actual crank, O P, whose extreme end describes the smaller circle, and the rod P L carries on the motion of the valve. The point P can be shifted along the arm O T, thereby varying the amount of travel of the slide, and the length of the rod P L can also be adjusted. In this way the effect produced by any deviation from the proper length of the eccentric rod can be studied. We are now prepared to trace out the diagram as given by an indicator. The crank being horizontal with the piston at the end of its stroke, the first thing to be done is to place the valve in the correct position for admitting steam, by setting back O P until the lap is allowed for. The valve then opens, and if the pressure of the steam is sufficiently maintained the indicator pencil will trace the steam line A B. When the crank gets to the

end of first dotted line, A is closed, expansion begins, the pressure falls, and we have the expansion line B C. At the point marked "release" the valve is moved so far to the left as to open a passage from A to C, and the release of the steam (exhaust) begins. The pressure falls from C to F, and continues very low till the point marked "compression" is reached, when B closes and the steam in the corresponding end of the cylinder is "cushioned" so as to increase its pressure, the pencil rising from M to A when the double stroke has been completed. The object and effect of putting "lap" upon a valve are two-fold: 1st, to give a free release to the exhaust steam, and 2d to produce a fixed amount of expansion.

The "lead," of which mention has been made, is outside lead, that is, it relates to the *admission* of the steam; but, of course, "lead" can be given to the exhaust side of the valve, in which case it is called *inside* lead. The four principal points in the valve motion are: 1st, the admission of the steam; 2d, the cut-off; 3d, the release or exhaust, and 4th, the compression or cushioning of the steam behind the piston.

PRACTICAL METHOD OF SETTING THE VALVES OF A LOCOMOTIVE.*

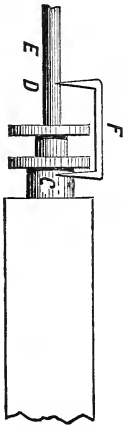
Before entering into a practical consideration of the subject before us, it may be proper to state the object of the writer in treating on the subject of Slide Valves, from the fact that there has been so much pre-

*Lyne.

viously placed before the public on the same subject; but the writers of these papers have failed to give the plain and practical instructions so much desired by the machinist. How often have we heard the desire expressed by this class of men for plain instruction, and it is our object to avoid all technical terms, and place in the hands of the machinist in the shop a course of instruction so plain that if it were spread before him, and strictly adhered to, any man of ordinary intelligence would be able to set the valves of a locomotive within a reasonable amount of time, and in a satisfactory manner. It is not our purpose to go into the details of designing and laying out the valve motion, for space will not permit; so we will only consider at this time, the series of operations performed in adjusting the valves. Conceive, then, that the engine has been placed upon the wheels. The wedges set up, links hung, and valve rods connected. The first step, under these circumstances, is to mark off the valve, which is done after the following manner: Move the valve back so as to open the front port, then move it ahead until it will admit a piece of the thinnest tin in the edge of the port; then, from the point C, Fig. 58, made with a center punch with a steel tram F, usually about 7 inches in length, describe a short arc on the valve stem and mark permanently with a center punch at D. Through this point draw a line parallel to the valve stem. Move the valve forward so as to open the back port, and then move it back until it will admit tin as in the previous di-

rections, and from the point C, as before, describe the arc E, also put a permanent mark at E, care being taken to make these points correspond with the points of the tram. These points will show the position of valve when the cover is put on the steam chest. We must now satisfy ourselves that the reach rod is the right length, by throwing the lever in the forward notch. Set the links plumb and measure from top of the link block to top of the slot in link, throw the lever in the back notch, set the links plumb and measure from bottom of block to bottom of slot in link; these measurements will show if the links hang high or low.

FIG. 58.



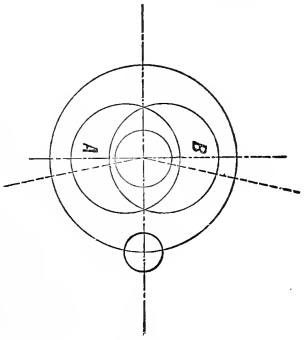


FIG. 59.

Practice has demonstrated that it is better to hang the links ⅛ in. high, as the wear is all down on the different parts. Care should be taken to take these measurements on both links, as it often occurs,

even on new work, that one link will hang higher than the other for various reasons, sometimes owing to a depression in one frame. If this is found to be the case, and the variation is but slight, the lowest side of the tumbling shaft may be raised by putting a liner under the bearing. If the arms should need any setting, this should be done before altering the length of the reach rod, as these alterations would conflict with each other. After the links are proved to hang alike, the height may then be adjusted by lengthening or shortening the reach rod, so that they hang according to previous directions.

The next thing in order will be to set the eccentrics, which may be done by commencing with the right hand side of the engine.

Place the crank on the forward center, then examine the marks on the straps, in order to see which is the forward and the back motion; as some builders put the forward motion eccentric next to the box, and *vice versa*, hence the necessity for this precaution. Practically, it is better to put the back motion next to the box, because the forward motion is then easier to get at, which is a great advantage, particularly when an eccentric slips while on the road, and the forward motion is the most important. We have often heard engineers curse the man who puts the forward motion next to the box. If the back motion is to be placed next to the box, move the eccentric up to within ½ in. of the box, and roll it around so that the belly, or throw, comes directly under the axle, as in Fig. 59,

where A represents the back motion. Then move the forward motion up to within ¼ in. of the back, and roll it so that the throw comes directly over the axle, as represented by B; this may be determined by the eye, as it is only a preliminary operation. It is advisable to leave ½ in. clearance between the eccentrics and box, so that they may not strike it and be loosened, and equally as necessary to have ¼ in. between them to prevent the straps from interfering. The eccentric rods may now be put on and the ends connected to the links. Of course the same directions will apply to both sides of the engine; and we also state that the eccentric in use always follows the crank when a rock arm is used, as it reverses the motion, and any alteration in the length of the rods must be made in the opposite direction from which it appears on the valve stem, in squaring the valves, for the same reason. After putting on the rods it is necessary to look in the steam chest, to see if the valve stands in the center of the seat, or nearly so, which will be seen at a glance; also, throw the lever forward and back, so as to try both motions. This precaution is very necessary, as the rods may be extremely long, or short, so that when the engine is moved the valve will strike the end of the chest or the link block, the top or bottom of links, and either strain or break some of the parts. We have seen this occur where the man in charge neglected this precaution.

If this examination is satisfactory the next step will be to take the dead centers. The main rods being

connected, we now move the engine ahead so that the crank on the right side stands about ⅛ in. from the end of the forward stroke, see Fig. 60, and make a center punch mark on the wheel cover at A. Care will be taken to place this point so that the marks made on the tire with the tram will be about 6 in. ahead of a line, G, passing through the center of the axle. The tram should be held level. This tram, B, is made of steel with sharp points, and usually measuring 14 in. With this tram from the point A, describe an arc, H, on the tire, then make a fine center-punch mark on the forward guide block, and with the short tram F from this point, describe a short arc on the

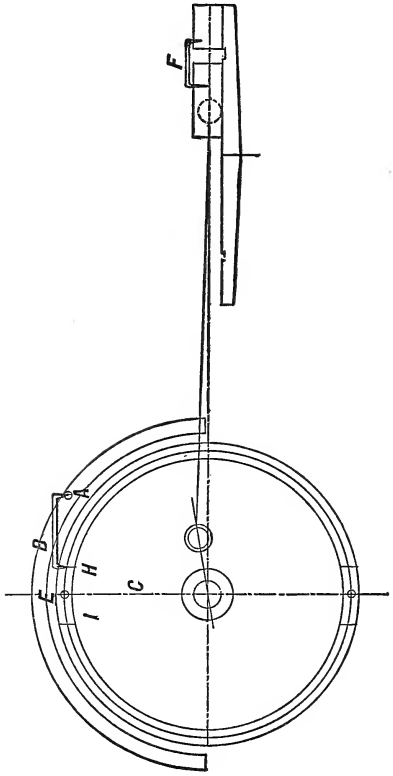


Fig. 60.

crosshead. Now move the engine ahead until the crank passes below the center, and the arc has also passed the tram about ¼ in., we of course hold the tram F in the same position, and now move the engine back carefully until the point of the tram and the arc on the crosshead correspond. It will be observed that both these points are taken with the crosshead moving towards the end of the stroke to obviate any difficulty which may arise from lost motion in the connections of the main rod.

With the tram B describe the arc I on the tire, and with another tram from the center of the axle, describe an arc cutting the arcs, H and I, at about the center of the tire, and with a pair of dividers find the center E between these two points. This will be the dead center required. Describe a small circle about this point to assist in finding its locality. These directions must now be followed to find the three remaining centers, after which we will proceed to square the valves or equalize the travel, which is done in the following manner: Throw the lever in the forward motion, commencing on the right side of the engine, move the engine ahead, holding the tram B in position until the point E on the wheel, and the point of the tram correspond with each other; this will be the front dead center. Then, with the tram F, Fig. 58, from the point C, describe an arc on the valve stem, with the longest part of it below the line, as shown in the figure. The object of this is to distinguish the forward motion from the back, observing to let the forward motion extend

below, and the back motion above the parallel line. This point being taken, we proceed likewise with the other three points, marking them in the same manner.

After finishing the four points in the forward, we proceed to take the same for the back motion, in this manner: Throw the lever in the back motion, and move the engine ahead until the center point on the wheel has passed the point of the tram B about 6 in., then move back carefully until the point fits the tram and mark the valve stem, as in the forward motion, only the longest part of the arc above the parallel line, (see cut), and so in their order, take the four centers in the back motion. Having taken all the eight points, we now examine the lines to see if the valves are square. With a pair of dividers from the point B take the distance to the nearest point, forward motion, and then place the point of the dividers in the point E, and see if the distance is the same to the nearest line for same motion. If it is, the valve is square, but if not, the difference must be divided, and if the valve travels too far ahead, the eccentric rod must be lengthened one-half the amount of this difference, and *vice versa*. In this manner go over the other points and mark the amount necessary to alter the rods upon them, with a piece of chalk. After adjusting the rods, it will be necessary to go over the same points again, and in the same manner, and so on, until the valves travel equally between the lines B and E. Always observe to rub out all except the permanent marks on the valve stems before going over the points, to avoid confusion. The

valves are now squared, and the next step is to give them the required lead, which is understood to be the amount that the valve must stand open when the crank is on the dead center. Some master mechanics proportion the amount of lead, so that when the lever is placed in the center notch the valve will have $\frac{5}{16}$ in. lead, which we believe to be a very good plan, for no definite rule can be adopted, as the rods of different engines are of different lengths, and the shorter the rod, the faster the lead will increase. In the case before us we will say $\frac{1}{16}$ in. lead is required at full stroke. On the points B and E, with the dividers, set off $\frac{1}{16}$ in. outside these points, by describing short arcs shown in the cut. Commencing with the right side, place the crank on the forward center with the lever in the forward motion. Slack the set screws in the forward motion eccentric, and roll it towards the crank indicated by the dotted line in Fig. 59, until the point of the tram F, Fig. 58, fits the small lead arc just outside the point B, and tighten the set screws in the eccentric. Now, without moving the engine, throw the lever in the back motion, slack the back motion eccentric, and roll it towards the crank until the same lead arc outside the point B corresponds with the point of the tram F, as for the forward motion. Then tighten the set screws in eccentric.

The engine should be moved over these points to see that they are not affected by lost motion, and very likely the forward motion will have to be readjusted, owing to the fact that rolling one eccentric throws the other out.

In the same manner set the left side and prove it The valves are now square and have the required lead, but we must ascertain if they will cut off square in each of the notches; therefore, we place a square on the guide, and draw a short mark corresponding to the end of the crosshead when the crank is on the center, which is called the traveled point. Throw the lever in the 10 in. notch, that being used more than the others generally, and hold the tram *F* in position, moving the engine ahead until the point accurately fits into the point *B*. Great care must be taken in testing these points as the crosshead may move some distance without showing much on the valve stem. Measure from the front travel, point to the edge of crosshead, and mark it on the cylinder, or steam chest near the front end, so as to remember it; and in the same manner test all the other points in the forward motion, marking them in the same manner. If, after taking all the points we find that they agree, the valves are right.

But it may happen, and does generally, that there will be a variation caused by the links being worn, etc. For example, we find on the right side that the crosshead will travel 10½ in. from the front travel point, and only 10 in. from the back. We here find that the cut-off takes place too quick on the back end; therefore, to equalize this, we are obliged to shorten the eccentric rods a trifle to cut off square. This, of course, throws the valves out of square in the full stroke notch, but practically, it is found to be the best way to remedy this evil. We may shorten the back

motion the most, as it is of the least consequence. On new work, the cut-off is adjusted by moving the saddle on the link, until the valves cut off square, but cannot be done on repairs.

To lay out the notches in a new quadrant it is only necessary to clamp the lever in position. For the forward motion give the link ½ in. clearance between the block and the top of slot, and ⅜ in. clearance between the bottom of block and bottom of slot. These measurements are to be taken when the eccentric is at the extreme throw. For the other notches move the cross-head so that it stands at the position where you wish to cut off, and move the lever until the valve cuts off, which may be determined by the tram in the points *B* and *E*. After clamping the lever fast, move the engine so as to test both sides, as in directions for cutting off. After the cut-off is adjusted, nothing now remains to be done but to fit and drive the keys in the eccentrics, and before moving the eccentrics they must be marked by a two-edged chisel, in order to replace them as they were before.

These marks must correspond on the axle and eccentric, and be made with great accuracy. We now examine the motion thoroughly to see that the parts are all secure; and some master mechanics put a piece of tin in all the eccentric rods after the foregoing operations, to allow for the expansion when the engine is hot. We have always found it advisable to set the valves when the engine is hot, or, if they were set when cold, to run over the points just before the engine leaves the shop.

This completes the operation of setting the valves.

CHAPTER XV.

LINK-MOTION AND VALVE GEAR.

THE link-motion valve gear of the present time is substantially what it was in 1833, as invented by the immortal George Stephenson. Its construction was and is now, about as follows:

On the driving axle are keyed two eccentrics *E*, so set that the motion of the one is adapted to working the valve when the engine is going ahead, and the other to work it when the engine is running backward. The former is connected through its straps and the rod *B*, to the upper end of the "link" *A*, while the second is connected in a similar manner with the lower end. By means of the handle (reverse bar) *L*, and its connections, and the counter-weighted bell-crank *M*, this link can be raised or lowered, thus bringing the] in on the link block, to which the valve stem is connected, into action with either eccentric. Or the link being set in mid-gear, the valve will cover both steam ports of the cylinder and the engine can move neither way.

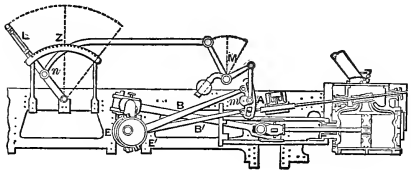


FIG. 61.

As shown in the cut, the engine is in position to run backward. A number of notches, Z, into either of which a catch on *L* can be strapped, enable the engineer to place the link in any position he choses. In intermediate positions between full-gear and mid-gear, the motion of the valve is such as to produce expansion of the steam.

To illustrate the subject-matter more fully, a most valuable paper on Link-Motions and Valve Gear, by Mr. Melville Clemens, is given in full:

LINK MOTIONS OF THE SLIDE VALVE.

The function of the "link" in valve gearing, is to reverse the engine's motion and to vary the degree of expansion of the steam, by governing the points and periods of its admission and release to and from the cylinders of the steam engine.

It is delicate in its operations, being materially affected by slight modifications, especially in regard to the mode of suspending it and the arrangements of its attaching joints and connections in the valve gearing.

In all valve motions a good link gear should produce through the valve, free admission and release of the steam, equally well for both the front and the back stroke of the piston, and be adjustable for such varied degree of steam expansion as will enable efficient use of the steam power, in all its positions.

Link motions, as used to operate slide valves, are of two classes or systems, known as the "*stationary link*" and the "*shifting link*." The stationary link is supported or suspended on a fixed point, and connected

direct to the crank shaft eccentric rods, reversing the engine, and the variable steam expansion is produced through it, by shifting up and down in the link, the "sliding block" of the valve rod or rocker arm. In the shifting link the link itself is shifted up and down on the block, to reverse the engine and to vary the steam admission and release.

Without entering fully into the elaborate series of diagrams and investigations which are necessary for a thorough study of link motions, the two systems of link motions may be shown by simple comparative diagrams and descriptions, making the subject readily comprehended in a general way, advantageously to those who may not have become familiar with it.

The diagram Fig. 62 is an illustration of the stationary link-motion, and Fig. 63 of the shifting link-motion.

In Fig. 63, A is the center of the crank and eccentric shaft of a steam engine; $A\,B$, and $A\,B'$, are, respectively, the crank positions at the commencement of the forward and back strokes of the piston. C, and C' are the fore and back eccentrics, which have their respective centers at a and a' when the crank pin is at B, and at a'' and a''' when the crank is at B'.

The fore and back eccentric rods are, respectively, at D, and D', when the crank is at B, and at D'' and D''', when the crank is at B'. E, is the link "open" and "coupled behind," at b and b', to the eccentric rods D and D', and supported at its center c, by the sustaining link F, on the transverse rock shaft d. The

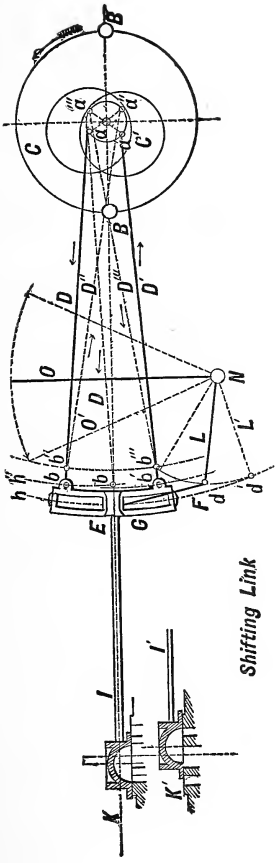


FIG. 63.

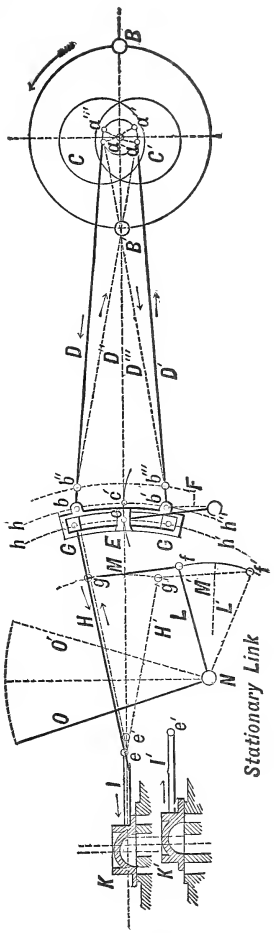


FIG. 62.

link is curved to the radius of the radius link *H*, and the radius link block *G*, slides in the curved groove of the link, moving from *G* to *G'*, as the radius link is moved from *H* to *H'*.

The reversing link *M* is pivoted at one end, *g*, to the radius link *H*, and at its other end, at *f*, to the reversing lever *L*, fast on the rock shaft *N*, operated by the hand lever *O*. The radius link *H* is pivoted at *e* to the valve rod *I* of the valve *K*. The valve is shown at *K*, in its position over the steam and exhaust ports of the engine cylinder, when the crank is at *B* at the commencement of the forward stroke; and the valve is also shown at *K'*, in its position at the commencement of the back stroke, when the crank is at *B'*.

It will be seen that by swinging the hand lever from the position *O* to the position *O'*, the reversing lever *L* takes the position *L'*; reversing link *M* akes the position *M'*; radius link *H* takes the position *H*,' and that the block *G* takes the position *G'*.

Now, when the block *G* is at the upper end of the link, or at "full gear forward," the valve will be governed in its travel by the fore rod *D*, as if it were driven by the single eccentric *C*; and the valve will distribute steam to the engine cylinder so as to drive the engine forward. But when the block is shifted to the lower end *G'* of the link, or in "full gear back," it will, in like manner, be governed in its travel by the lower or "back" eccentric rod *D'* and back eccentric *C'*, and the engine will run backwards. When the block is at *c*, the middle of the link, or at "mid gear," its travel

will be governed equally by the fore and back rods and eccentrics, it having, in that position, about one-half the travel which it has when in gear at G and G'. When the block is at positions in the link, intermediate between its middle and its ends, its travel will partake more of the motion of the eccentric rod to which it is nearest, operating to run the engine forward when the block is above the middle of the link, and to run it backward when placed below the middle of the link.

The stationary link gearing is thus adapted to move the valve so as not only to reverse the engine, but to vary the distance of the valve's travel, without varying its lead or linear advance. It is, therefore, evidently adapted for variable expansion, or variable periods of steam admission, suppression and release, for each stroke of the piston.

In setting out the stationary link-motion for any given travel and linear advance of the valve, the eccentrics must be of such diameter, and their angular advance of the crank be such that, taken in connection with the length of the eccentric rods and the link, the horizontal motion of the ends of the link, at points b and b, shall be equal to the travel of the valve when in full gear; and so that the horizontal distance $b\,b''$ or $b'\,b'''$ (representing the linear change of position of the link, as the crank pin is changed from B to B') shall be equal to two times the linear advance of the valve.

In Fig. 63, illustrating the shifting link-motion, the valve and mechanism is, as far as practicable, the same

as in Fig. 62, and the same literal references are used, in order to aid in comparison of the two systems of link-motion.

The principal distinction in the features of the operation of the two systems is, that in the stationary link the valve has unvarying lead and linear advance; while in the shifting link the valve's lead and angular advance varies with every change of the position of the link.

The diagram shows the sliding block *G*, fixed on the end of the valve rod *I*, at "mid gear" with the link *E*. The link and eccentric rod joints are in the position *b* and *b'* shown in full lines, when the crank is at *B*, and when the crank is at *B'* they are at the positions *b''* *b'''*; so that the horizontal distance *b b''* or *b' b'''* is equal to the change in position of the valve and link at those two positions of the crank.

The horizontal motion of the link, due to the eccentrics, is least at the center of the link, at which point it is equal to twice the linear advance of the eccentrics, or the distance *b b''*.

The travel of the valve when in full gear, either front or back, is equal to the full throw of the eccentric moving it;—that is, when the link is open at the end to admit the block to move so as to bring the valve rod in line with the fore end of the eccentric rod.

The varying lead of the valve, produced by shifting the link, may be observed by inspection of the diagram. The full lines show the valve in mid gear, with the crank at *B*, the commencement of the forward stroke.

If now the link be shifted down so as to bring the valve in full gear forward, the connecting point b, of the fore eccentric rod and link, will fall at b_4, and the valve be drawn back towards A, a distance equal to the horizontal distance of point b_4 from the dotted circle $b\ b'$ (central at A); thus lessening the lead of the valve by that distance, in changing from mid gear to full gear.

By constructing larger scale diagrams, the varying lead due to shifting the link, may readily be found in a similar way.

The motion of the valve by the stationary and the shifting links and double eccentrics, is substantially the same as that from a single eccentric of variable throw and advance, when the valve gearing is properly proportioned and suspended.

CHAPTER XVI.

VALVE MOTION DIAGRAMS.

THE outside circle (Fig. 64) is the crank-pin circle, the smaller one the eccentric's center circle. The crank-pin circle is divided off into the inches of travel of piston, by a tram or pair of compasses set to rep-

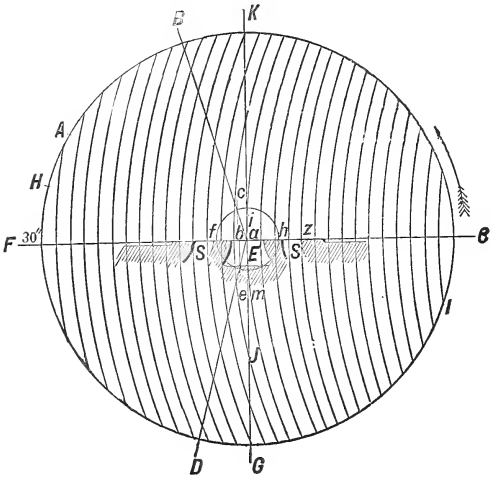


FIG. 64.

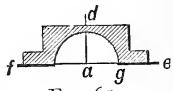


FIG. 65.

resent the rod's length. S S, in Fig. 64, are the steam ports, E the exhaust port, and X X the bridges. Fig. 65 is a sectional elevation of the valve divided by the

line *a d*. The valve drawing is cut out at the line *f e*, and placed on the line representing the valve-seat.

The laps and lead are laid off (from the pin C, the valve rod running directly from the eccentric to valve) *a b* from center of circles, *a*. The line *b c* is erected perpendicular to center line F C, and through where it cuts eccentric circle at *c* a line is drawn, as *a* B. This line is the center line of eccentric, and the angle C *a* B —the angle formed by eccentric and crank *c*. This angle is constant in whatever position the crank-pin may be.

Place the valve, Fig. 65, on the seat, so that line *d a* coincides with line *c b*, and you have position of valve when crank is on center. As the crank moves, in direction of arrow, from C, the valve moves from right to left, and back again, till right-hand edge of valve comes to edge of port, *z*. The steam is now cut off, and, to find position of crank-pin, notice that the line *a d* on valve cuts the center line, F C, at *b*, which, extended down to small circle, cuts it at *e*. The line *a e* D is now evidently the centre line of eccentric. Taking the distance, B C, in a pair of compasses, and measuring back from D, we find the point A, which is the position of the crank-pin when steam is cut off. The valve now continues to move from left to right till edge of exhaust cavity, *g*, comes to edge of port, *h*, when the exhaust commences. The center line on valve *d a* now cuts line F C at *a*; this, extended down, cuts eccentric circle at *m*. A line, *a m j* G, now represents the center line of eccentric; laying off the distance, BC,

from G, we find the point H of crank-pin, when exhaust commences. The crank now travels on the lower half of its circle. The valve continues to travel from left to right, opening into the exhaust until the edge of exhaust cavity again comes to *h* (edge of steam port, the valve now traveling from right to left), the exhaust is closed and compression commences. This occurs, as before stated, when *g*, on valve, comes to *h*, on ports; the line *d a*, on valve, then cuts the line F C at *a*, and the line *a i* K represents center line of eccentric. Lay off from K the distance B C, and we find I, the position of crank when compression commences. Similar points on the opposite stroke can be found by commencing with crank-pin at F instead of C, noting that center line of eccentric is down instead of up. If the eccentric's motion is transferred to valve through a rocker shaft, the lap and lead must be laid off *toward* the crank-pin instead of from it.

These points, I assume, are understood by the reader. The irregularity of the valve's motion (more expansion occurring on one end than the other) can be ascertained by this diagram. Unless the eccentric rod is *very* short, no notice may be taken of its irregularity due to radius (shown in line *b c*, being struck from length of eccentric rod), as it is so little that, generally, a straight line, as *b c*, will suffice for practical purposes.

I trust that this may be of use to some who have worried their brains with impracticable formulas and diagrams produced by men more scientific than practical, and which resemble puzzles.

MOTION CURVES.

The laying off of motion curves presents to the eye *all* of the movements of the valve at a glance. Fig. 66 shows the diagram after it is completed, ready to

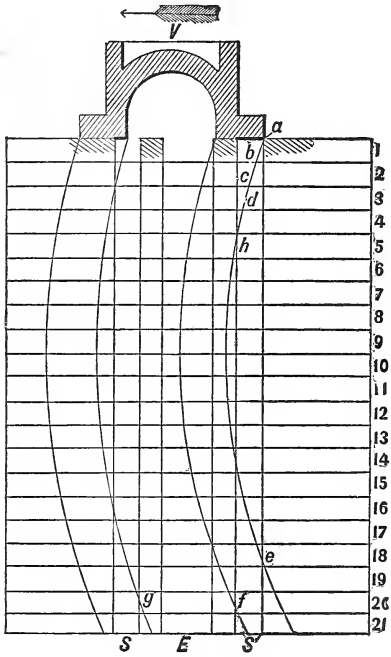


FIG. 66.

file away for future reference. Elevations of the ports are laid out to a scale and in length equal to the stroke of the piston, with the inches marked as shown. We start with the valve V, as shown at the commence-

ment of the stroke, and, by means of the diagram (Fig. 64) previously, described or by other means, get the position of the valve for several positions of the piston, or for each inch, as shown at *a*, *b*, *c*, *d*. When all of the positions are obtained and jotted down on the port elevations, a curve that cuts them all is drawn, as are similar curves, for the other edges of the valve. The opposite curves can also be laid down, and the movements of the valve for the opposite stroke obtained. In the diagram shown, we see that the port S′ was wide open at *h*, or 4½ in. of piston travel, that steam was cut off at *c*, 18 in.; exhaust opened at *f* 19½ in., and compression commenced at *g* 19½ in. also, the valve being "line and line." Other points can be obtained by inspection, and the diagram forms valuable data for the builder and user.

CHAPTER XVII.

THE PISTON AND ITS RINGS.

We come now to the piston and the method used for packing it so as to prevent any steam from passing from one side to the other.

The piston shown in Fig. 67 is the one in general use, and which has been the standard for many years notwithstanding its many well-known defects. Its

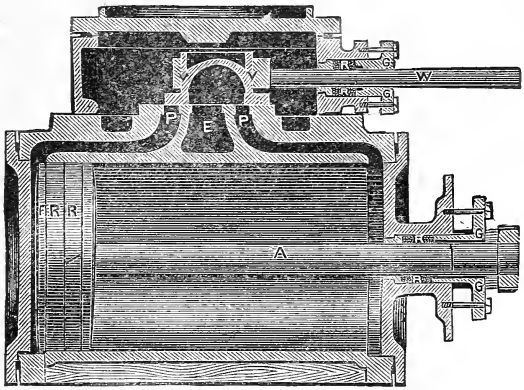


Fig. 67.

construction is about as follows: It is made of cast iron and is cast in two pieces. The main body to which the piston rod is attached is called the piston head, and the other part (marked F), which is used to

keep the rings in place, is called the follower, and is attached to the piston by means of bolts called follower-bolts. These follower-bolts are generally made of composition, but steel ones are stronger and better and not so liable to be twisted off. The piston is made to work steam-tight in the cylinder by means of two packing rings (marked R R) made of cast iron or brass, generally the former. These rings are turned a little larger than the diameter of the cylinder and then cut diagonally (as shown in the figure) so that they can be set out or expanded to fill the cylinder completely by means of steel springs set out by bolts. The place where one ring is cut is placed opposite to that of the other so as to break the joint, which is done to prevent the steam passing through one joint from passing through the other. There is another ring made of cast iron, and as wide as both the others, placed on the inside, which furnishes a bearing for the springs and causes them to press equally against the outer rings. The inner ring is cut also.

This piston is now being rapidly superseded by an improved piston (as shown in Fig. 68), which shows the piston wrought in one solid piece, and dished out so as to form a deep surface of contact with the sides of the cylinder. Here the depth of the guiding surface of the piston is four inches, and the three grooves shown in section are intended for the reception of metallic packing rings, as applied by Mr. Ramsbottom, about 1854, and which form the simplest method that has been devised for keeping the piston steam-tight

under the high pressure employed in locomotive engines. The contrivance is thus described in a paper on an improved piston for steam engines: "Three separate grooves, each 1/4 inch wide, 1/4 inch apart, and 5/16 inch deep, are turned in the circumference of the piston, and these grooves are fitted with elastic packing rings. These rings, which may be of brass, steel, or iron, are drawn of a suitable section to fit the grooves

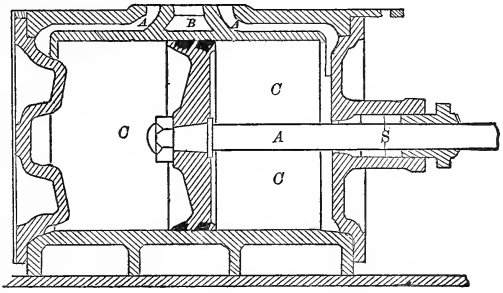


FIG. 68.

in the piston, and are bent in rollers to the proper curvature, the diameter of the circle to which they are bent being about one-tenth larger than the cylinder. They are placed in the grooves in a compressed state, and along with the body of the piston are thus put into the cylinder, care being taken to block the steam port. The rings are therefore forced outwards by their own elasticity, which is found quite sufficient to keep them steam-tight." Of course the rings are put on so as to break joint. One object in the construction of this particular piston has been to reduce as much as possible the amount of rubbing surface. It is a maxim

in books on mechanics that the amount of friction is independent of the extent of surfaces in contact; but that rule only applies where the surface is directly supporting a pressure, and it has nothing to do with the friction of a piston, where an increase of surface undoubtedly increases the friction. Here the lightness of the piston reduces the friction, and so also does the small amount of elastic surface pressed against the interior of the cylinder.

As to the amount of bearing surface, it appears that for an 18-inch piston it would come to about 42 square inches, whereas in a piston of the same diameter with 2½-inch packing rings the area of rubbing surface would be 141 square inches. The simplicity of construction is also an advantage, the only workmanship expended on the piston being that of turning its rim and forming its centre. The packing rings are drawn as ordinary wire, and are afterwards bent into shape, the cost of production being very small.

The mode of attaching the piston-rod is apparent from the sketch. There is a shoulder, and the rod terminates in a coned end, the whole being screwed up tight by a nut. The cylinder covers are copies of the configuration of the piston, thereby avoiding a waste of steam.

CHAPTER XVIII.

INJECTORS.

The injector was invented by M. Giffard, of France. The invention of the injector for supplying feed-water to the boiler of an engine is principally remarkable as presenting an illustration of the direct conversion of heat into work. Before describing the apparatus it will be necessary to explain the meaning of the term "induced current."

Looking back historically it appears that in 1719 Hawksbee, the inventor of a double cylinder air-pump, showed that when a current of air was sent through a small box—entering by an opening at one side near the top and escaping by a corresponding opening at the opposite side—the effect was to rarefy the air within the box rather than to compress it. It is an old experiment to suck up and drive a jet of spray out of a bottle by blowing through a horizontal tube with a contracted nozzle whose end is placed just over a vertical tube dipping into water contained in the bottle. The current of air passing over the open mouth of the vertical tube carries away some of the air from inside the tube, whereby the water rises to the top and is dispersed in a jet of spray.

According to theoretical definitions the particles of gases repel one another and have no coherent action

among themselves. In practice this is not the case: and if a definite current of air be set up in a mass of air at rest, as when a jet escapes from the mouth of a tube, the air in motion will drag a number of the quiescent particles with it, and will extend considerably the dimensions of the original current. It will, in technical language, induce a current also in the surrounding air.

The application of an induced current, with which we are now concerned, is exhibited in Fig. 69. The globular vessel represents a boiler in which high pressure steam is generated, and from which it escapes at an orifice, E. The steam is discharged just inside a conical casing or nozzle, the object of which is to provide a means for setting up an induced current of air which will speedily exhaust the tube. The water forced up by atmospheric pressure to supply the loss of air, will, therefore, issue from E, and we shall have made the first step towards the construction of an injector, viz., the discharge through E of a mixed jet of steam and water. Fig. 70 shows a Giffard injector, as made by Wm. Sellers & Co., Philadelphia, Pa. There is a pipe marked "steam," which terminates in a vertical conical nozzle, having within it a solid rod or needle capable of contracting in any degree the amount of the issuing jet. On the opposite side of the apparatus is a pipe marked "water," which

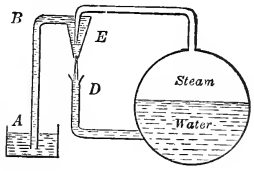


FIG. 69

corresponds to A B in the elementary diagram, and by turning the wheel marked "water regulator" the tinted sliding tube is brought up or down, so as to regulate the supply of water which is sucked up by the inducing action of the steam. There is here, therefore, precisely the apparatus already described, together with the mechanical means for regulating the supply of steam and the supply of water.

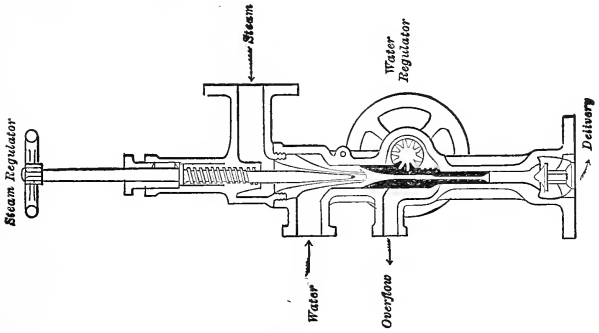


FIG. 70.

At one end of the injector is a valve opening outwards, leading to the flanged and marked "delivery," which is in direct communication with the boiler. This valve is shown open in the figure, but it is closed by the pressure in the boiler when the injector is not at work.

Looking again at Fig. 69, which is intended to show the action in its most simple form, we may point out that M. Giffard discovered that a jet of mixed steam and water, issuing from E under the circumstances above stated, is competent to overpower and drive

back a simple jet of water issuing from the opening D, and that a supply of feed-water may be forced into a boiler by the steam generated therein without the use of any pumping apparatus whatever.

Since action and reaction are equal and opposite, it is abundantly clear that a simple jet of high pressure steam issuing from E could never drive back a jet of water issuing from D under the same pressure. It was a great step in science to conceive the idea that the absorption of heat which took place at E could furnish a source of energy directly available for doing work. There has been no parallel to this discovery in any analogous direction, and it is difficult to account for the action.

On the steam side there is the kinetic motion of the molecules of steam, and on the water side there is the motion of translation of a quantity of water, and the problem is to show a possible method of passing from the one to the other. Now, the steam issuing at E has a velocity many times greater than that of the water forced out at D. The instant that steam is liberated and escapes, the kinetic motion of its particles appears under a new form, viz., as a motion of translation, and the velocity of an issuing jet of steam is many times greater than that of a jet of water forced out by the same pressure. If, therefore, the jet of steam could be condensed by an indefinite source of cold after it had fairly got clear of the orifice, it would be converted into a fine liquid line, and the velocity with which its molecules were rushing out would not

be changed. The motion of heat would be diminished, but the onward motion would remain unimpaired. This liquid line would be moving at such a high velocity that it would pierce any jet of water coming towards it from the boiler, very much as if it were a steel wire forcing its way through the mass. We know of no source of cold competent to produce this result, but what really happens is the same in character though less in degree. The steam, liquefied at E, retains to some extent the higher velocity which it possessed as steam, and on the whole the aggregate energy of the water globules flowing onward at E is greater than that of the water jet coming towards them from D. The latter jet is overpowered and driven back, and a quantity of water from the cistern at A is continally forced into the boiler.

As to the velocities with which we have to deal, it appears that if the steam had an actual pressure of six atmospheres the water would issue at a velocity of about 101 feet per second, and the steam at a velocity of about 1,800 feet per second.

Referring again to Fig. 70, it will be seen that a pipe marked "overflow" leads out from the centre of the instrument; this pipe communicates with a small chamber in the central channel just below the level of the pinion, and is intended to allow the escape of any surplus water. When the supply of steam is properly adjusted to the amount of water sucked into the instrument, no overflow takes place, whereas an access of water or steam will at once give rise to a discharge

at the overflow. In the one case the energy imparted to the water is insufficient and part recoils, while in the other case too great a condensation of steam will occur and energy will be dissipated. It is, however, easy to adjust the steam and water regulators so as to avoid any waste.

The rise in temperature of the feed-water shows the amount of energy available for doing work, and it is found that the quantity of water delivered into the boiler increases as the feed-water itself is supplied in a colder state. Thus, in one case, the temperature of the feed-water before entering the injector was 60°, 90°, 120°, and the number of gallons of water delivered per hour was 972, 786, 486 respectively. It is a confirmation of the explanation that steam at a given pressure will force water into a boiler against a still higher pressure. Thus, steam at 27 lbs. pressure forced water into a boiler where the steam was at 52 lbs. pressure, the temperature of the feed-water being raised from 92° to 170° during the operation.

THE "1876" INJECTOR, BY WILLIAM SELLERS & CO., PHILADELPHIA, PA.

The introduction of the Giffard injector in this country was made by William Sellers & Co., of Philadelphia, in 1860, and they were, during the continuance of the original patent, the sole licensees and manufacturers under that patent in the United States, and have made from time to time improvements in the instrument. In 1865 they introduced the novel and important principle of self-adjustment. Previous to this, injectors

had either fixed nozzles or were arranged with independently adjustable nozzles, separately operated to adapt the steam and water-supply to each other, and to the changes in the boiler pressure, etc. In these injectors any want of proper adjustment was indicated either by a waste of water or in-draught of air at the overflow, and if, after a most careful adjustment of the parts to produce the best results, the steam pressure in the boiler changes, the instrument would work badly until readjusted for the new conditions. The self-adjusting instruments have no waste at the overflow. After starting, the steam-supply alone is adjusted by hand, and the water-supply is automatically regulated, so that the steam is always combined with the exact quantity of water necessary to produce the best results, no matter how much the steam pressure in the boiler may vary. This instrument in its improved form went through various changes for the better up to the year 1876, when a new style, the "Injector of 1876," was exhibited at the Centennial, after careful tests on leading railroads.

The advantages of using an injector to feed steam boilers are, that it may be operated to deliver the water in a continuous stream, and furnishes heated water at all times. To obtain the full advantage of the injector the manipulations of the instrument required to start and regulate the feed should be simpler than those necessary in the use of the pump. The "Injector of 1876," a sectional view of which is shown in Fig. 71, was designed to accomplish this object, and is put in

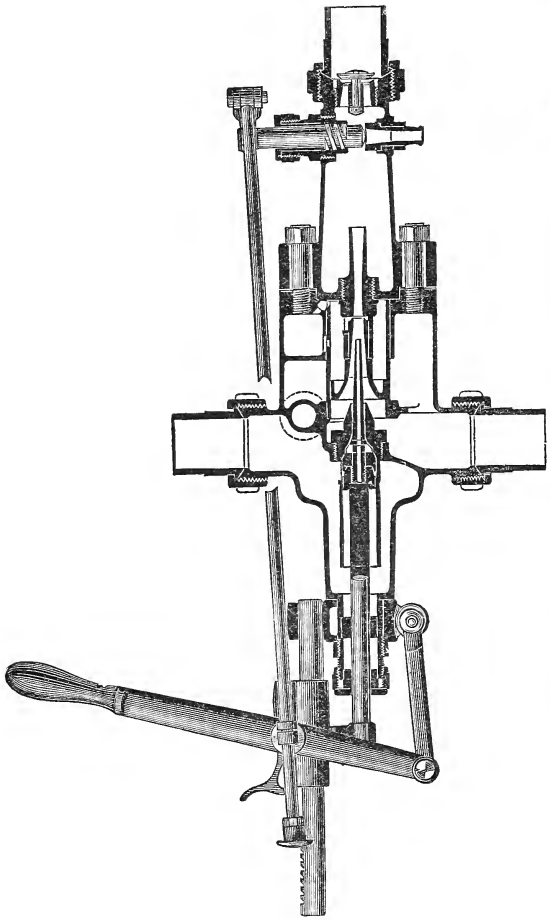


FIG. 71.—SELLERS INJECTOR OF 1876 (*Sectional View*).

operation and regulated entirely by moving a single handle. The connection to the boiler, and those for

the admission of steam and water, are clearly designated in the figure, the latter being provided with a suction chamber to steady the flow. A fixed receiving-tube, through which the principal jet of steam passes, is regulated by the position of the interior conical spindle. The annular jet of steam combines with water in the combining-chamber, and the concentrated jet is forced through a delivery-tube, and the check-valve shown, to the boiler. The combining-tube forms part of the piston, which fits freely into the case, and the smaller end of combining-tube slides freely also in the end of delivery-tube. The pressure of the water is on one side of the piston, and the other side is in communication with the jet issuing from combining-tube through an opening inside of delivery-tube. If the water-supply be too great, a portion escapes through an opening and accumulating in the surrounding chamber, forces the piston and combining-tube towards the receiving-tube, and contracts the annular space between the two latter, so that the water-supply is reduced. If the water-supply be insufficient, a partial vacuum will be produced in the chamber, and the piston moved to admit more water. In this manner the supply of water is automatically adjusted to suit all the requirements.

The description thus far is common to all the Sellers' self-regulating injectors. In the "Injector of 1876," the central spindle shown in the receiving and combining-tubes is secured to an operating-spindle, and has a small bore throughout its length, which

receives steam through small openings, when the valve on operating-spindle is raised from its seat in the top of the larger valve, which admits steam to the receiving-tube around the central conical spindle. The operating-spindle is moved through the arm and slide shown, by the operating-lever; and the latter, also, by means of the rod, with stops upon same, operates the screw overflow-valve on stem. In the position shown, steam is shut off, and the overflow-valve is open. Upon moving the lever the valve is first opened, and the steam is first admitted to the small bore of central spindle, and issues in a jet, which induces a current in the water-supply pipe, whereby the air is withdrawn—water lifted and expelled at the overflow. [The lifting effect desired is quite dissimilar from the action of the annular jet in operation as a boiler feeder, being more nearly allied to the action of the exhaust in producing a draught in the smoke-pipe of a locomotive, and requires a high velocity and free expansion at the moment of escape.] When the water is lifted by moving the handle still more, a collar on the central spindle comes in contact with and opens the large valve, thereby admitting steam to the annular jet to produce regular operation, as previously described, and the handle, upon being moved back to its extreme, strikes the stop on the rod, and thereby shuts the overflow. At the same time a pawl drops into a rack on the arm, and holds the lever in position when the latter is pushed in to regulate the flow. This pawl is lifted and caught fast when the lever is pushed entirely in to stop the

injector, and not relieved again till the lever is at the other extreme, as above explained. The instrument can be located in any convenient position on the locomotive above the water-level, as it is considered advantageous to have the injector lift its supply of water.

THE HANCOCK INSPIRATOR.

The Hancock Inspirator, Fig. 72, differs in some important respects from the instruments commonly classed under the head of injectors. It consists essentially of a lifting-jet and lifting-nozzle, combined with a forcing-jet and force-nozzle or injector, steam being admitted to both of these nozzles whenever the inspirator is in operation, to deliver the supply-water to the force-nozzle, and to force it through this nozzle into the boiler. Although both the lifting and force-nozzles are fixed, their proportion one to the other is such that the inspirator requires no adjustment for changes in steam-pressure or water-supply, the waste-valve being kept closed while the instrument is in operation, except at the time of starting. The sectional view of the stationary inspirator, Fig. 72, will serve to explain the action of the instrument. In this figure, A is the steam-supply pipe, connected to the steam-space of the boiler; B is the water-supply pipe; and C is the feed-pipe, to which is connected an overflow or waste-pipe with waste-valve, these latter connections not being shown in the figure. D is the lifting-jet, E the lifting-nozzle, G the forcing-jet, and H the force-nozzle. This latter nozzle is somewhat analogous to the combining-tube of an ordinary injector. F and I are stop-valves,

the first controlling the admission of steam to the forcing-jet, and the latter determining the course of

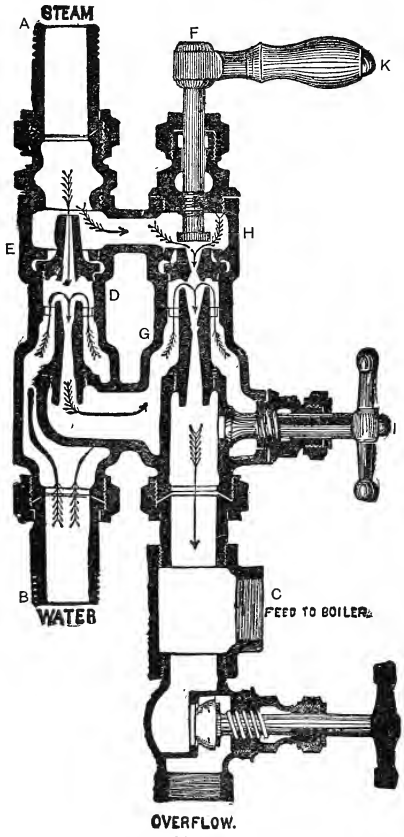


FIG. 72.

the water delivered by the lifting-jet. The action of the inspirator can perhaps be most simply explained

in connection with a description of the manipulation required to start the instrument. In the figure, the inspirator is represented in operation; but when it is not working, a steam-valve in the pipe A, not shown, is closed, as is also the valve F, while the valve I and the waste-valve are open. Opening the valve in the steam-supply pipe A, steam is admitted to the lifting-jet D, drawing water through the supply-pipe B, and discharging it through the lifting-nozzle E, valve I, waste-valve, and overflow-pipe. As soon as water issues from the overflow-wipe, the valve I is to be closed, when the supply-water will pass through the force-nozzle H, and will escape at the overflow. The valve F is then to be opened, by moving the lever K one-quarter turn, and the waste-valve is to be closed, when the water lifted and delivered to the force-nozzle H will be forced into the boiler by the steam issuing from the forcing-jet G. If the water supply is to be varied, this can be effected by partially closing a valve in the supply-pipe B without throttling the admission of steam; or both the steam and water may be throttled if desired. In practice, however, the delivery is varied by throttling the water-supply. Whatever changes of adjustment are made, whether of steam or water-supply valves, within the capacity of the inspirator, the instrument will continue in operation with the waste-valve closed. In this respect the inspirator differs materially from fixed-nozzle injectors, which cannot be operated with the waste closed, under the conditions recited above.

THE RUE LITTLE GIANT INJECTOR, MADE BY THE RUE MANUFACTURING COMPANY, PHILADELPHIA, PA.

The principle of its operation is as follows:

As the steam is coming from the boiler, it enters the steam plug. Here it is joined by the water, which enters and fills the combining-tube; here the steam gives the water a velocity, is condensed, and a water jet is formed and driven across the overflow space, and enters the discharge plug; thence past a check-valve, which is generally placed a few inches from the injector, into the boiler.

During the passage of the water from the combining-tube to the discharge plug, as it passes over the overflow space, if too much water has been supplied to the steam, some will escape, and flow out of the overflow nozzle; for the reason that the pressure of steam is not great enough to give that amount of water the necessary velocity, in order that it may have sufficient power to overcome the resistance of the boiler pressure; hence, the water and condensed steam, or mixture, as it is generally termed, must pass out at the overflow.

This will go on until we reduce the water-supply. This is done by moving the lever to the right, which will move the combining-tube nearer to the steam plug, thereby reducing the supply of water until the steam can give it the required velocity, and, when this has been obtained, there will be no discharge of water at the overflow.

The injector being at work perfectly, we will sup-

pose that the pressure of steam has been gradually increasing, which likewise increases the velocity of the water in the combining-tube, until it is driven through faster than it can be supplied, and air will be drawn in at the overflow; but this is prevented by the small check-valve. Whenever this occurs, we are generally warned by a peculiar sound coming from the injector.

This will go on until the amount of water is not sufficient to condense the steam, and be at a less temperature than 212° Fahr., which will cause the formation of steam, which is very light, although, with its high velocity, it has not sufficient power to overcome the boiler pressure, and must, consequently, pass out at the overflow in the form of a very wet steam, so to speak.

From the above it will be seen that although the velocity of the mixture of a temperature above 212° Fahr., or when the formation of steam takes place, is much higher than that of a mixture in which this formation does not take place, the power of the former is much less than that of the latter, "because the total actual energy is proportional to its *weight* multiplied by the square of its *velocity*."

To illustrate this in a very simple way, let the reader procure two wooden balls of the same size, one of hard and heavy, and the other of a soft and light wood.

Either of these balls will float on the surface of a body of water, and it will require some force to sink it; but take them up, and throw the heavy one, for

example, with some velocity upon the water, and it will sink to a considerable depth before the resistance of the water will overcome its momentum or actual energy. Now take the light one and throw it with the same velocity, and it is doubtful if it will sink more than a few inches. This goes to show that the weight has a great deal to do with the power of the mixture, in the working of the injector.

Another important point that should not be overlooked is that of the temperature of the feed-water.

So long as it is desirable to have the operation of the injector as perfect as possible, the temperature of the feed-water should not exceed certain limits, as it is necessary that the steam should be completely condensed.

In order that this may be as perfect as possible, and the operation of the injector the same, the feed-water must be cold enough to absorb the proper number of heat units that the steam contains, and be at a less temperature than 212° Fahr.

It may be well to state here that the operation of the injectors of the ordinary form ceases; that is to say, they will not do the work, after the mixture reaches or exceeds 200° Fahr.

The greatest temperature of feed-water will, generally speaking, depend upon the pressure of steam. When the pressure of steam is high, the temperature of the feed-water must be lower than when the pressure is low. The greatest temperature of feed-water, in either case, can best be determined by experiment.

By carefully considering the foregoing, it is obvious that the amount of water that the injector throws must increase in proportion to the amount of steam used, when the temperature of the feed-water is raised.

It is obvious that it requires a greater amount of water to condense the steam, and be at a lower temperature than say 195° Fahr., than it would if the temperature of the feed-water were lower.

From what we have already stated, it will be seen that when the amount of water is large in proportion to the amount of steam, the velocity of the mixture

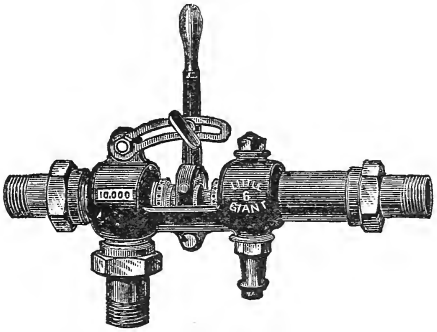


FIG. 73—THE RUE LITTLE GIANT INJECTOR.

also diminishes. This also applies to the above, when the temperature of the feed-water is raised.

With a certian pressure of steam and temperature of feed-water, the power of the mixture may be just sufficient to overcome the boiler pressure; whereas, if the temperature of the feed-water is still increased, it will require a proportional amount of water to con-

dense the steam; this will result in a proportional reduction of velocity, probably sufficient to render the power of the mixture valueless.

When the injector, shown in Fig. 73, is set so as to lift the feed-water, it is started by placing the lever in a vertical position, and opening a small jet-valve which allows the steam to pass through a small pipe attached, which is connected to the small pipe, through which the steam also passes; and in so doing, draws all the air out of the injector and water-supply pipe, thereby creating a vacuum, which results in the pressure of the atmosphere raising the water in the pipe, and through the combining tube, thence out, and immediately appears at the end of the nozzle.

As soon as the water appears at the overflow nozzle, the main steam valve is gradually opened until it catches the water, when it is opened wide, and the small jet-valve is closed.

Should no water appear at the overflow, it shows that the injector is working all right.

Now, should the pressure of steam increase until the temperature of the mixture is high enough to cause the formation of steam, and a discharge of the same at the overflow, we must increase the water-supply until this discharge ceases; after the discharge ceases it may be preferable to still increase the supply of water until there will be a discharge of water at the overflow; then gradually reduce the supply of water —for this reason, that in the former case you may have admitted just sufficient water to keep the tem-

perature of the mixture below, say 195°, and you may not have given it all the water that the stream would safely carry into the boiler.

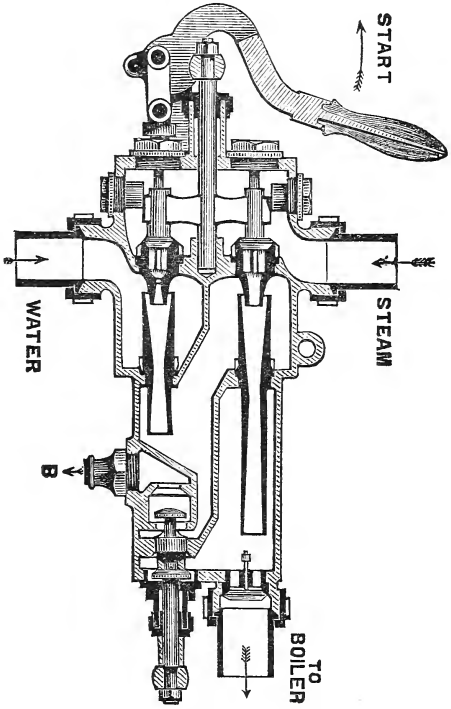


FIG. 74.—THE KORTING UNIVERSAL INJECTOR.

THE KORTING UNIVERSAL INJECTOR.

As will be observed by Fig. 74, the instrument is a combination of two steam-jet apparatus; the first one proportioned for lifting and delivering the water

under some pressure into the second one, where its velocity is sufficiently augmented to overcome the counter pressure of the boiler. The explanation of the proper working of the injector, at the lowest as well as the highest steam pressures, without any adjustment of parts, is found in the fact, that the quantity of the water taken in by the first apparatus and delivered to the second one is directly in proportion to the pressure of the steam, so that the first one acts as a governor for the second one.

The explanation of the feeding of hot as well as cold water, is found in the construction and proportion of the first apparatus, which has a proportionately small steam nozzle to insure high suction, and as the water is delivered to the second one under pressure, its temperature can be corresponding to this pressure, and may be delivered into the boiler above the boiling point. At the same time the combined area of the two steam nozzles is smaller than that of any other injector of the same capacity, so that its duty must necessarily be higher.

This combination of the two apparatus, and its self-governing qualities without moving parts, makes the apparatus the least sensitive—a great desideratum on locomotives.

The limits of admissible temperature are: Feed-water 150 deg. Fahr. delivered into the boiler, with 150 lbs. steam at 250 Fahr. Injectors will lift water up to twenty feet, according to temperature.

Fixing the Injector.

The injector should, preferably, be fixed horizontal, in which case it will drain itself when not in operation. The pipe should not be smaller than the corresponding size of couplings. The dirt-stop should always be attached where the water is not perfectly clear. There should be a steam stop valve, and a main check valve on boiler. If water flows to the injector, it is necessary to have a stop valve in the water pipe.

Before connecting the injector, have the steam pipe well blown out with steam to clear it of scale and dirt. Do not omit to attend to this, as the nozzle openings are small, and if clogged with red lead or dirt, will interfere with, or stop the action of the injector.

Manipulation.

If the injector has to draw the water, open with handle A, half-way first, till water is discharged through the starting cock B, then open full.

This stop need be of so short duration, that a continuous moderately slow movement will accomplish the required result; so that the instructions for manipulation would read: To start, open with handle A; to stop, shut with handle A. To regulate the quantity of water to a minimum, throttle the water in suction pipe, but keep steam turned on full all the time. Manufactured by Schutte & Goehring, steam jet engineers, Philadelphia.

THE KEYSTONE INJECTOR,

Manufactured by E. Tracy, Philadelphia, Pennsylvania.

The following are some of the advantages claimed for this injector:

1st. Its simplicity, durability, and easy adjustment, requiring no skill to operate it.

2d. It is not affected by overheating, and will work under any pressure of steam from 5 lbs. to 160, and is not liable to break while working.

3d. It is void of all stuffing boxes. No extra fittings required for the two classes A and B.

4th. Its advantages over pumps. It is far cheaper. It is not necessary to run engine to fill boiler, as with engine or belt pumps; thus saving fuel, repairs, oil, etc.

5th. The water by the use of this injector is heated to 200° Fahrenheit, hence no heater is necessary, and can be dispensed with, although it will feed through a heater same as pump.

6th. It will raise water as high as any other make, and can be regulated to supply more or less water as the case requires.

7th. Will lift and work water as hot as any other injector.

Non-Suction Injector "A."

This injector, Fig. 75, is used where the supply is received from a pressure, such as street mains, reservoirs, etc.

Method of Connecting.

It should be placed in a horizontal position, and lower than the tank, if water is taken from such, so it will receive a full supply. All pipes should be of the

same internal diameter, to correspond with the injector coupling. Attach the steam pipe to highest part of boiler, and as short as possible, to obtain dry steam; but in no case make attachments to pipes supplying an engine, pump, etc., as it causes a variation in the steam pressure. Place an ordinary globe valve on steam pipe, a valve or water cock on water-pipe. (There is no necessity for an extra check valve on feed

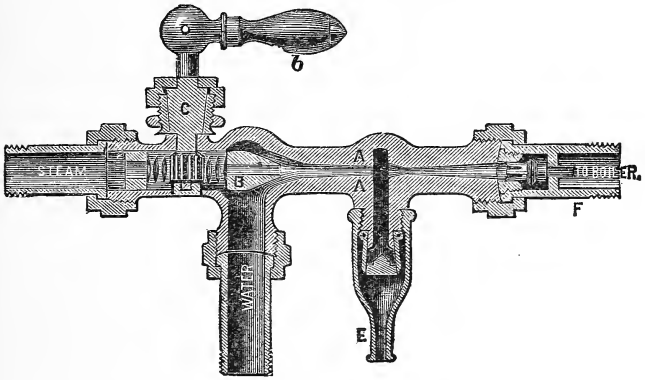


FIG. 75.—Non-suction Injector, A.

pipe near the injector, as there is one in the swivel marked to boiler).

Use no washers or packing, as all joints are ground. Be particular, and remove all scale, cuttings and dirt from pipes, and see they are in perfect working order before connecting.

Method of Working Class "A."

First. Open the steam valve to let out any condensed steam there may be in the pipe, and close it

again. Then open the water cock, then the steam valve, and move the plug B slowly forward with the handle *b*, until the water ceases at the overflow. If, while the injector is working, water should escape from the overflow, move the plug forward to reduce the supply of water. If steam escapes, move the plug backward, to give it more water. When the lever *b* is set so the injector works perfectly dry, if you wish to stop feeding, close first the steam valve, then the water cock.

It is not necessary to disturb the lever *b*.

When wishing to feed again, the injector is put in operation by simply opening the water cock, then the steam valve. The lever is used to regulate the steam and water, and the necessity of using it will be shown at the overflow. If the lever *b* moves too loosely, tighten the nut upon spindle C: if too stiff, loosen it. This injector will force water through a heater.

The Suction Injector "B."

This class, Fig. 76, is applied where there is no pressure or head of water. For instance, when the feed-water is taken from a low cistern, river, pond, etc.

Method of Connecting.

Place the injector in a horizontal position, and great care should be taken to have all joints air-tight; and it is best to place a piece of wire-cloth on the bottom of the water-supply pipe, to prevent floating particles from entering the injector. The jet D, used in this injector, serves to create the vacuum, and assists in

carrying the water into the boiler; it being stationary, is always in proper position to produce a vacuum; and the steam necessary to carry the water into the boiler is simply obtained by moving the plug *b*, without affecting the position or operation of the jet. All pipes should be of the same internal diameter; attach the steam pipe to the highest part of the boiler, as in class "A;" place an ordinary globe valve upon steam pipe; no valve or cock upon the water-supply pipe;

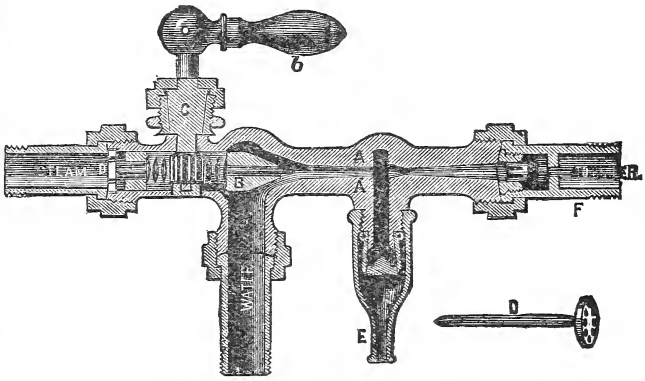


FIG. 76.—The Suction Injector "B."

see that all scale, cuttings or dirt are removed, and the pipes are in proper working order, and there is no dirt upon the plug B, or disk of jet D, to prevent the proper closing of the perforations.

Method of Working Lifting Injector "B."

Open the steam valve to remove the condensed steam; then close it again; move the plug B back tight against the disk of the jet D; then open the

steam valve, and when water appears at the overflow, move the plug slowly forward until it ceases to flow. These injectors will lift according to their size.

FRIEDMANN'S INJECTORS.

Foremost amongst the distinguishing features of these injectors is the intermediate nozzle, by which the water supply is conducted in two annular streams to the condensing chamber of the injector, where the steam jet is subjected to the action of both at separate points. The result of this double action is the complete and effectual condensation of the steam jet, and the transfer without loss of all its inherent power and velocity to the water, now united in one column, and making its way with irresistible force and projection into the boiler.

The first stream also becomes a motor of the second, and carries it along without further expense of steam; this, it is claimed, explains the marked difference in the quantity of steam needed to work these injectors in comparison with others.

Nearly all the other makes of injectors now before the public have but one waterway; in consequence of which, the water-supply reaches the steam jet in a whole, unbroken mass, and coming in contact with this large body of water, the momentum of the steam jet is checked to a great extent and often only partially condensed, expands in the mass of water after passing the receiving nozzle; this breaks and confuses the column seeking to penetrate the boiler, and is the cause of much trouble and annoyance.

The Friedmann Injector, on the contrary, with the double waterway, before described, with fixed nozzles, and no movable parts to get out of order, and having no *cam motion, no sliding or rolling levers, and no ground joints or packing* to require frequent adjustment, delivers the water with a steady, uninterrupted stream that no amount of jarring or disturbing influences can break or confuse, while the water-supply lasts, or steam is kept up.

These injectors are lifting and non-lifting, as shown in the Figures 77 and 78.

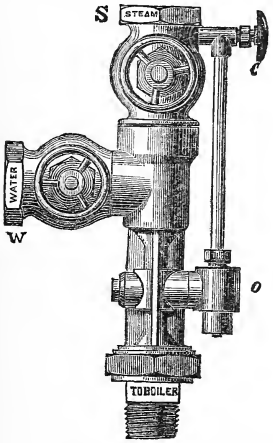


FIG. 77.—Friedmann's Lifting Injector.

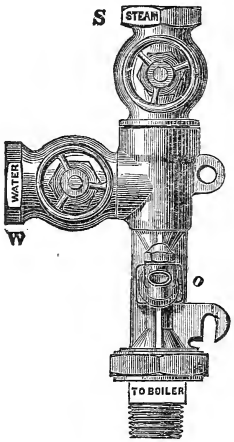


Fig. 78.—Friedmann's Non-Lifting Injector.

Special attention is called to the important fact that by a recent improvement in the lifting injectors without increasing their cost or impairing their capacity to supply the boiler, they are enabled to lift water from the unprecedented depth of 25 to 28 feet if required.

Every injector is supplied with an overflow valve, which prevents air or dirt from entering the boiler.

Method of Working Lifting Injector.

Be sure the water valve or cock W is open; then

1st. Open the small jet valve J, with low pressure full, with high pressure partly, until the water flows out of the waterflow at O.

2d. As soon as the water appears at the overflow, open the main steam valve S gradually, and close the small jet valve.

Should water still be discharged from the overflow, as may be the case where the steam pressure is low, reduce gradually the water-supply by the valve W until the discharge ceases.

To stop, close the main steam valve. This injector may also be used as a non-lifting where a head of water is available. While the injector is inactive the steam valve should be kept closed.

Method of Working Non-Lifting Injector.

To start, 1st. Open the steam valve S a little, to let the condensed water in steam pipe out through the overflow O, and shut again as soon as clear steam appears.

2d. Open the water valve W.

3d. Open the steam valve S slowly, and the injector is working.

Should any water waste out of the overflow after the injector has started, reduce gradually the water-supply by the valve W until the discharge ceases.

To stop, close the steam valve S and the water valve

W in the above-named order. Maximum temperature of water which the injector will feed, 140 degrees. The injector being at rest, the water valve W and the steam valve S should be kept closed.

General Instructions for Attaching Injectors.

1st. All the pipes, valves, and fittings must be of the full size to correspond with the number of the injector, as laid down in the table of capacities in the maker's catalogue; except when the water has to be draughted from a longer distance than ordinary, the suction pipe should be a size or more larger than the injector fittings call for.

2d. All joints and connections must be perfectly air-tight.

3d. A strainer should be fixed on the end of the water supply pipe to prevent the admission to the injector of foreign matter, such as chips, shavings, weeds and such like.

4th. A globe valve or steam cock is necessary on the steam supply pipe, between the boiler and injector, and a check valve and stop cock on the delivery pipe between the injector and boiler.

It is very necessary that the connections should have a few bends as possible, and that the pipes invariably be round.

5th. That all pipes and connections must be blown out clean. This is of vital importance, as dirt and pipe cuttings cause nine-tenths of the leakage of new valves. The steam for the injector should be taken from the dome or top of the boiler.

CHAPTER XIX.

MANAGEMENT OF LOCOMOTIVES.

A WELL built engine, having its parts easily accessible, and possessing good qualities for the production of steam may, with careful management, be made to run a long time with but little expense for repairs. The points to which the engineer directs his attention are the manner of firing, the supply of feed water, and the proper adaptation of the production of steam to the features of the road, and various other particulars of a like nature which are necessary for the proper performance of a locomotive. It is, of course, necessary to fire up oftener when the load is heavy than when it is light. The fire should be maintained at a proper point to make sufficient steam, and should not be permitted to get so low as to affect the pressure in the boiler.

It is an object, however, in approaching a terminal station to have just enough fire to reach the round house. The supply of feed water is regulated very much by local circumstances on the road. In ascending grades the injection of much cold water would check the formation of steam, and it is therefore necessary to have a good supply of water in the boiler be-

fore reaching the foot of an unfavorable grade. On long levels and descending grades one injector can be kept working constantly. There should be plenty of water in the boiler before reaching a roadside or terminal station. The furnace door should be kept open as little as possible, as the entrance of the cold air through it contracts the tube sheets, and is sometimes the cause of them leaking. If the engine has a variable blast it is a good plan to open it full when firing, and to immediately contract it very much so as to recover the fire quickly.

The cylinders and valves require to be oiled at about every fifteen or twenty miles of the run. If the ports of the throttle-valve are of the same area as the steam pipe, it is found best to keep the throttle partially closed, as when the pressure is rather less than in the boiler the engine is not so apt to prime. The proper opening for the throttle of any engine can soon be determined by observation. In going through covered bridges or station houses the dampers should be closed, and the draft otherwise checked to guard against fire.

The boiler should be blown out at intervals of a week or more—depending very much on the purity of the water used. When a scale deposits on the tubes and crown sheet, a little coal oil (refined) will help to remove it.

The frequent use of the sand box has the effect to rapidly wear away the tires of the wheels, and therefore should only be used when it cannot be dispensed with.

The best way to clean the wood work about an engine from grease and dirt is to use spirits of turpentine or refined coal oil on a handful of waste. To clean brass work, take a tablespoonful of oxalic acid and put it in a quart bottle of water. Wet a piece of waste with this acid water and go over the brass work, merely wiping it; afterwards go over again with a piece of dry waste or woollen cloth dipped in lamp-black or pulverized rotten-stone. As oxalic acid is a deadly poison, it should be handled carefully, the bottle properly labeled, and not left lying around loose. In polishing bright work, use only the finest grades of emery cloth.

LOCOMOTIVE FIRING.

A locomotive engineer who prides himself, in connection with his fireman, as to their economy in the use of fuel, writes that his success is due in a large measure to the fact that he breaks his large lump coal up as fine as nut coal before using it, and by so doing gets 20 per cent. more steam out of a ton of coal than he did when using coal as it came, regardless of size. He also says his fireman pays special attention when throwing fuel into the furnace to drop it just where needed, the secret of successful firing being to have an even fire all over the grate.

CHAPTER XX.

KEYING UP LOCOMOTIVE SIDE AND MAIN RODS.*

When it is necessary to key up a main rod, the first thing to do is to take it down, after placing the engine on the center on that side. It would be well to ascertain now if the travel slots in the guides are correctly located. These slots are for the purpose of preventing the cross-head from forming a shoulder on the guides, and they do this by the cross-head traveling half the width of the slot past its inside edge, if the rod is of the right length. Their province is not, as many engineers think, to lead off the oil forced to the end of the guides by the cross-head. To ascertain if they are correctly located, pinch the cross-head to each end of the guides (after the main rod is down) till the piston-head strikes the cylinder head. Then make a mark even with the end of the cross-head on the guides. If these marks are equally distant from the travel slots, they (the slots) are correctly located and can thereafter be used to key the length of the rod too. The rod being down, the pins should be calipered across their horizontal diameter when the engine is on the center, because the pin wears smaller across its horizontal diameter when it is on the top or

* Smith.

bottom quarter, as the piston's pressure is most effective on the pins at this point; and if the boxes were reduced to this diameter they would evidently bind when on the pin's greater diameter; that is, when on the center. If the pins are much out of round they should be corrected with a file. Having calipered the pins as above, take this diameter in a pair of inside calipers. Lay the boxes "brass and brass" and by the inside calipers ascertain how much must came off to allow them to bear on the pin, remembering to take half the amount as indicated by the inside calipers from each brass. Having filed off what is necessary from the boxes, place them in the strap on the pin and drive the key till the boxes are "brass and brass." Then if they can be revolved easily by hand on the pin they are right.

They should not, however, be filed so as to allow of their standing apart when keyed up, but should touch each other. The key may now be slacked back, the brasses shifted to the open end of the strap, and a piece of stiff putty placed on the inside crown of the strap, and the key driven till the joint of the brasses stands in line with the center of the oil hole in the strap. The key should be marked even with the strap, and the strap and boxes disconnected from the pin. The thickness of the putty will indicate the thickness of the liners necessary to be put in. When the joint of the brasses is in line with the center of oil hole the length of the rod should be right if the rod is made right.

Perform the same operation on each end of the rod; put it up and drive the keys to the marks made on them, and then try the length of the rod by pinching the engine past the centers, when, if the cross-head travels an equal distance past the edges of the travel slots in the guides, the rod is of the correct length. If not, its length should be altered (by inserting or taking out liners, as the case may be) till correct when tested by the travel slots, if they are correct.

It is obvious that the rod must be just right when keyed by this plan. The brasses should always be "brass and brass," as they will run much longer. After taking down the side rods, the wheel centers should be trammed and equalized by the wedges, if they are not correct. The wedges should be up snug when keying the side rods. If there is much lost motion in the side rods, the back pins will be found to be behind when the tram is placed on the pin centers. They should, therefore, be slipped till the tram will drop into the pin centers. This can best be effected by taking the weight off from the back wheels with a couple of jacks under the foot-board. The boxes may be reduced to the pins the same as the main rod, leaving them "brass and brass."

The front end of rod may be put up, the joint line of brasses coinciding with center of oil hole in strap as for main rod. Then put up the back end, shifting the boxes in the strap with the two keys in the back end till the rod can be shaken with both hands. This plan first reduces the brasses to the pin, leaving them loose enough when keyed, "brass and brass."

The front end is put up with liners forward of the forward box, till the boxes coincide with center of oil hole in the strap, and the back end is put up and adjusted by the two back keys till the rod can be shaken.

The engineer knows, therefore, that the boxes themselves are not tight on the pins, and as the rod is loose enough to be shaken, it is proven that the keys have not been driven so as to tend to force apart or draw together the pins, hence the rod is right.

Another plan much in use after filing the boxes is to drive the forward key which forces the back box of the front end to the pin. Continued driving of the same key forces the rod back which draws the front brass of the front end up to the pin, and also forces the front box of the back end to its pin, the back key of back end being then driven to force the back brass of back end to the pin. The back key goes down twice as fast as the other keys, as it has not only its own lost motion to take up, but that also of the forward boxes which is thrown upon it when the whole rod goes back.

The writer assumes that the side rod has three keys, two between the pins and one back, and that the main rod has two keys between the pins. When the side rod has four keys the forward key of front end takes the place of the liners.

Side rods on switching engines and on road engines, if the track is rough, should be run loose, as the driving boxes shift up and down in the jaws to a greater

extent than otherwise, and as this changes the distance between the pins, the loose side rods accommodate this change.

In ten-wheelers, the side rods should be keyed from the front end back and not, as is sometimes the case, the other way, or partly back and partly forward.

In the plan given for keying side and main rods, it is necessary to take the rod down each time it is keyed, as the plan leaves the brasses "brass and brass." This is the better plan, as the boxes then have all of the advantages of a solid box, together with that of adjustment. The writer remembers a case in which the engineer, adhering rigidly to the "brass and brass" plan, did not find it necessary to touch his side rods but once in from eighteen to twenty-four months, depending on the service of the engine.

CHAPTER XXI.

WHAT TO DO WHEN THE LOCOMOTIVE BREAKS DOWN.*

THE locomotive engineer who is "posted" knows or ought to know just what to take down and what to do when an accident occurs. Nothing is more galling to an engineer than to bring his engine in with the half of her on the tank, when one-fifth of the disconnection carried in that way would have answered better. The idea held by so many engineers that the more of their engine they take down the more safely she can come in alone, is, of course, wrong, as each part so disconnected leaves some other part either better or worse off. The following suggestions may be of value in such emergencies:

When an engine gets off the track, the first thing to be done by the engineer, if he is not disabled, should be to pull his fire, if the position of the engine is such as to leave the crown-sheet or flues uncovered with water. If the ash-pan is jammed, or if from any other cause the fire cannot be pulled or dumped, it may be smothered by shoveling green sod, sand, earth, or snow

* F. C. Smith.

into the fire-box. If the engine cannot be replaced without the help of another engine, the side and main rods should come down to prevent them from being sprung. If the engine is still on her wheels it will generally be found that she can be got back on the track more easily the way she came off. In case of a broken side-rod, disconnect the broken rod and the opposite side-rod also. This is all that is necessary. The necessity for taking down the opposite rod is that if only the broken rod is removed and the pin on that side is on either quarter, the pin on the opposite side being on the center cannot start the back drivers through its side-rod, should the forward drivers slip in starting; the result being that the back drivers, not being compelled to slip with the forward ones, would remain nearly stationary, the front pin would pass the center, shortening the distance between the pins, and the rod would bend or the pin break, necessarily.

If the main rod breaks, disconnect it; block the cross-head at the back end, disconnect the valve stem and tie it to the hand rail if it has a joint, and then go ahead. It would be as well, in connection with the above, to pull the valve clear back so as to open the front port, or cover both ports with the valve, jamming the gland on the stem by screwing up one side only.

The plan frequently adopted by engineers after taking down the main rod is to place the piston at the back end of the cylinder, open the front port, and jam the gland on to the stem to hold it in position. This plan is a poor one, as the valve may shift, and then a

bad cylinder head is the result. Always block a piston or cross-head at the back end of the guides, for if the blocking should get loose, the front head, which is the cheaper, would alone suffer. A better plan than carrying blocking for the cross-head is to have the blacksmith make a hook out of 1½-inch round iron, also a flat piece or bar 15 inches long, 1½ or 2 inches thick, and 4 inches wide, with a hole through its center for the shank of the hook to pass through—the shank being threaded for a nut. When it is necessary to block a piston, get it to the back end of the guides, pass the hook round the cross-head wrist and the shank through a hole in the other piece which rests against the face of the yoke supporting the back end of the guides, run up a nut on the shank of the hook hard against the bar, and the piston is secured. Two nuts are better than one, the outside one being jammed on to the other.

If a leading wrist-pin breaks, the main and side rods on that side and the side rod on the other side must come down, the piston must be blocked, and the valve stem disconnected. In case of the breaking of a back pin, both side-rods must come down.

If a valve stem breaks, take it down, also the main rod on that side, in the meantime blocking the piston. If the stem is broken outside of the chest, let the piece remain in the stuffing-box, fill in some packing, and screw up the gland.

If the back-up eccentric rod breaks, take both eccentric rods down on that side of the engine. If it is a

go-ahead rod, it alone may come down with the straps, also the main rod and valve stem on that side. The main rod and valve stem should also be disconnected in the case of a broken back-up eccentric rod, and in either case the link should be disconnected from the tumbling-shaft by disconnecting the hanger.

If the lifter tumbling-shaft, arms, saddle-pin, or reach-rod breaks, a piece of wood may be fitted and tied in between the block and top of the link slot for the link to rest on. The piece should be long enough to raise the link to cut-off where the engine is desired to run.

In case of a broken reach-rod or tumbling-shaft, both links must be blocked up as described. As the engine will then have to be held entirely with the brake, great care will be necessary.

For broken eccentric straps or eccentrics, proceed as in case of eccentric rods. For a slipped eccentric—assuming it to be the go-ahead one, and the engine a link engine—put the engine on the center on the side of the slipped eccentric, pull the reverse lever into the full back-up notch, mark the valve stem flush with the gland with a knife blade, throw the lever in the full go-ahead notch, turn the slipped eccentric till the mark on the stem reappears in the same position as when marked, notice that the slipped eccentric is not in the same position as the back-up eccentric, but the full part or belly nearly opposite, and then go ahead.

In the case of a broken spring hanger, the broken spring should be removed, unless an extra hanger or a

chain is carried, in which case the end of the spring may be held by the new hanger or the chain, it being necessary to jack up the back part of the engine, under the foot-board, to take the weight off and allow the insertion of the hanger or chain. If neither hanger nor chain can be had, slip a block of wood or rubber under the end of the equalizer, thick enough to raise it about level, the weight being removed from it by jacks under the foot-board. If the engine has far to go, or has a train to pull, it will be best to put a block of wood over the driving-box, between it and the frame, and over the wheel where the hanger is broken, to ease the other spring. If jacks are not carried, the driver may be run on to a stick of wood 4 or 6 inches in thickness, placed under the forward wheel to take the weight from the back wheel, and *vice versa*.

A broken spring should be treated the same as a broken spring hanger.

A broken equalizer should be removed, as it may get into the wheels, also the springs and wooden pieces placed over the driving boxes to keep the frame up.

A broken tire, if clear off, requires the wheel center to be kept from the rail, either by running the wheel on to a block of wood, or by jacking up under the wrist-pin and fitting a piece of wood between the oil cellar and pedestal brace. The two side-rods should come down if the tire is a back or forward one, and also the main rod on that side. If the engine has far to go and a train to pull, it is better to remove the oil cellar and fit a notched piece of wood in its place to

give a proper bearing for the shaft, as otherwise the shaft will rest on the thin edges of the oil box—a bearing entirely insufficient, if any distance is to be run, or a load pulled. The writer has seen engines brought in with broken tires and the shaft running on the oil cellars, the bearings being so badly cut as to make it necessary to remove the wheels, re-turn the bearings, and fit new driving-box gibs or brasses.

It should be remembered that whenever the main rod is disconnected, the piston must be blocked and the valve stem disconnected.

A broken front truck wheel or axle can usually be chained up with the help of jacks under the front end, so as to get on a side track. The engine should be run very slow.

An unshipped throttle requires that the steam pressure be reduced, pulling the valve stem into the middle notch to shut off, and when taking water, the driving wheels to be blocked with sticks of wood when the tender is in the right position.

A burst flue can be plugged with a wooden plug, or, better still, with an iron one held in a pair of tongs or some special device for that purpose.

If a driving axle breaks so as to leave the wheels in position, the engine may generally be run alone on to a side track, and extra wheels and axles sent for.

A broken cylinder head requires that the main rod on that side should come down, and the ports covered by the valve and the valve stem disconnected.

If the steam chest or branch pipe in front end breaks,

a piece of two-inch plank with a rubber gasket beneath it should be bolted to the "nigger-head" or "T-head," the branch pipe being removed. The main rod should be disconnected on that side.

If the steam pipe breaks inside the boiler, the same means may be employed as for an unshipped throttle.

A broken flange on a truck wheel requires very slow running.

If a tender axle or wheel breaks, that end of the truck may be chained to a tie placed across the apron of the tender, blocking being placed between the tie and body of the tank to ease the strain on the apron. Both ends of the tie should be chained to the truck.

The above will cover the ordinary mishaps to which locomotives are liable, and which can be remedied by carrying out the suggestions recommended.

CHAPTER XXII.

HOW MUCH WILL A LOCOMOTIVE PULL?

It may be stated, generally, that the means by wnich a locomotive exerts its power in drawing trains is simply the friction or adhesion of the driving wheels on the rails; or to quote from Pambour's old "Treatise on Locomotive Engines:" "Two conditions are necessary in order that an engine may draw a given load. First that the dimensions and proportions of the engine and its boiler enable it to produce on its pistons, by means of the steam, the necessary pressure, which constitutes what is properly termed the power of the engine; and, second, that the weight of the engine be such as to give a sufficient adhesion to the wheels on the rails. These two conditions of power and weight must be in concordance with each other, for if there be a great power of steam and little adhesion, the latter will limit the effect of the engine, and there will be steam lost; if on the other hand, there be too much weight for the steam, that weight will be a useless burden, the limit of the load in that case being marked by the steam."

In the early days of locomotives it was thought that the adhesion or friction of the driving wheels on the rails would not be sufficient to enable such machines

to exert their full power, and many contrivances of toothed wheels and mechanical legs of various kinds were devised and experimented with.

In Wood's "Treatise on Railroads" (1838), the author speaks of adhesion, exclusive of the power requisite to drive the engine itself—in the best engines as $\frac{1}{15}$ part of the weight on the driving wheels; and in ordinary engines as $\frac{1}{20}$ of the weight." Pambour (page 252), puts the maximum adhesion at $\frac{1}{6}$ of the weight, but adds that "the force of adhesion is always at least $\frac{1}{20}$ of the adhering weight." Rankine (Treatise on the steam engine, page 529) gives the adhesion at from one-twentieth to one-fifth, and adds that one-tenth may be considered an average ordinary value."

Perhaps the figures which are most used in practice are those published in Molesworth's "Pocket Book of Engineering Formulæ," page 124. These are as follows:

ADHESION PER TON OF 2,240 LB. ON THE DRIVING WHEELS.

When the rails are very dry	600 lb. per ton
When the rails are very wet	550 " " "
In ordinary weather	450 " " "
In misty weather, if the rails are greasy	300 " " "
In frosty or snowy weather	200 " " "

In D. K. Clark's "Manual for Mechanical Engineers," page 724, he gives a report of experiments made by M. Poirée on the Paris and Lyons Railroad with a wagon by skidding the wheels. Of these experiments Clark says:

"At speeds under 20 miles per hour it appears from the table that, when the rails are dry, the co-efficient of friction, or the adhesion, is one-fifth of the weight, and that on very dry rails it is one-fourth. As the speed is increased, the adhesion is reduced. These data are corroborative of the results of the author's experiments on the ultimate tractive force of locomotives on dry rails, from which he obtained a co-efficient of friction equal to one-fifth of the weight, at speeds of about 10 miles per hour."

It will thus be seen that the co-efficient of adhesion, as given by these authorities, varies all the way from one-twentieth to over one-third. It is no wonder then that a young engineer in taking up this subject should be a little perplexed to know what data to take in making his calculations. Even if he leaves out the maximum and minimum and takes what these authorities regard as "an average ordinary value," he will be still very much perplexed. Thus Wood gives $\frac{1}{15}$, Rankine, $\frac{1}{10}$, Molesworth and Clark $\frac{1}{5}$. In fact, the differences are so great that we are led to believe that some or all of these writers must have been quite mistaken in their facts or their theories on the subject. Recent experiments have made it plain that such was the case.

In reading what these writers have written on this subject, it is nowhere apparent that they made any distinction between sliding and rolling friction, or static and dynamic adhesion. Now every locomotive runner knows that after an engine begins to slip its wheels it will not exert as much power as it will before they be-

gin to slip. In other words the adhesion of the wheels is much less when they slip than when they roll without slipping. Now most of the experiments which have been made to determine the adhesion of driving wheels have given the sliding friction of the wheels on the rails, and not their adhesion when they roll and do not slip. The first is dynamic and the last static friction.

Fortunately the experiments of Mr. Westinghouse and Captain Galton have thrown a great deal of light on this subject, and they have shown in the most conclusive way not only the great difference between these two kinds of friction, but also that the one, at least, is very much affected by the speed and also by the time. That is, they have shown that at a high speed the friction is much less than at a low one, and that it is considerably less after some seconds than it was at the beginning. This confirms the ordinary every-day experience of locomotive runners. The fact that until recently the distinction between these two kinds of friction has not been recognized is doubtless the reason for the great discrepancies in the data relating to this subject.

In the paper "On the Effect of Brakes upon Railway Trains," read by Captain Galton before the Institution of Mechanical Engineers, the following determinations of the adhesion of wheels are given. It must be kept in mind, too, that he makes the distinction between "adhesive" and sliding friction. By "adhesive" is meant the friction between rolling wheels and the track.

"On dry rails it was found that the co-efficient of adhesion of the wheels was generally over 0·20. In some cases it rose to 0·25 or even higher. On wet or greasy rails, without sand, it fell as low as 0·15 in an experiment, but averaged about 0·18. With the use of sand on wet rails it was above 0·20 at all times; and when the sand was applied at the moment of starting, so that the wind of the rotating wheels did not blow it away, it rose up to 0·35 and even above 0·40."

This is probably the most correct determination of the adhesion of wheels that has ever been made, and shows that the ordinary rule of taking the adhesion at one-fifth of the weight in the driving wheels is quite within the limits of ordinary practice. Even on a wet or greasy rail, with the use of sand, it was above 0·20 at all times. In fact, if we want to calculate the maximum power which a locomotive will exert if the rails are sanded, we might take the adhesion at one-third, and would be quite safe at one-fourth.

In order to put these figures in a form in which they can easily be remembered and conveniently used, they may be given as follows:

ADHESION OF LOCOMOTIVES.

Under ordinary conditions, without using sand on the rails, or on wet, sanded rails	One-fifth the weight on the driving-wheels.
Under favorable conditions, without sand	One-fourth the weight on the driving-wheels.
On a dry, sanded rail . . .	One-third the weight on the driving-wheels.

These may be taken as working data, but before we can apply them and answer the question which forms the title of this chapter it must be known how much power is required to draw a given load over a road with known grades and curves. If the authorities be consulted with reference to this point, a wider difference even than that relating to the adhesion of driving wheels will be found to exist. Without comparing these, it may be stated that the most recent experiments have shown that the resistance of good American cars does not exceed 6 lb. per ton of 2,000 lb. at very slow speeds on a straight and level track, and when in the best condition and good weather it is probably not over 4 lb. The wind, however, has an important influence, and as this is very variable, it is hardly safe to take the resistance under the conditions named above at less than 6 lb. per ton.

With reference to the influence of speed on the resistance, it must be admitted that our knowledge is very inexact, and probably the law or laws which govern it are not understood. The following rule, though, will give results which do not differ materially from those given by the most reliable experiments which have thus far been made.

To get the resistance per ton (of 2,000 lb.) of a train on a straight and level track at any given speed: Square the speed in miles per hour, and divide by 170 and add 6.

To get the resistance per ton due to any grade. Multiply the rise in feet per mile by 0·3815, and add

the quotient to the resistance due to the speed on a straight and level track.

Our knowledge of the resistance due to curves, like that due to speed, is in a very unsatisfactory condition, but the most reliable information we have indicates that the resistance is equal to about half a pound per ton per degree of curvature.

We may then tabulate these calculations as follows:

RESISTANCE OF TRAINS.

On straight and level track at very low speeds . . .	6 lb.	per ton of	2,000 lb.
For resistance due to speed: Square the velocity in miles per hour and divide by 172	. . lb.	"	"
For resistance due to grade: Multiply the rise in feet per mile by 0·3815	. . lb.	"	"
For resistance due to curves: Add ½ lb. per degree of curvature	. . lb.	"	"
Total	. . lb.	"	"

If the radius of the curve is given, the "degree" may be found approximately by dividing the radius into 5,730. This rule is correct enough for ordinary curves of over 500 feet radius.

Having these data, suppose we want to calculate how much, say, a Consolidation engine will pull up a grade of 70 feet per mile, with 9° curves and at a speed of 20 miles per hour. The first question to determine will be whether we want to know the maximum load

which such an engine will draw, or what it will do in good weather, or what it will do at all times. In the first case we would take the adhesion at $\frac{1}{3}$ the weight on the driving wheels; in the second at $\frac{1}{4}$, and in the last case at $\frac{1}{5}$. We will assume that the second represents our hypothetical case, and that the locomotive has a weight of 11,000 lb. on each driving wheel, or a total of 88,000 lb. The adhesion would therefore be one-fourth of 88,000 lb. = 22,000 lb. The train resistance per ton would be as follows:

Resistance on straight and level track = 6·0 lb.		
"	due to speed $=\frac{20\times20}{172}=$	2·3 "
"	" " grade $=70\times0{\cdot}3815=$	26.7 "
"	" " curve $=9\times\frac{1}{2}=$	4·5 "
Total		39·5 "

Therefore, as each ton will have a resistance of 39·5 lb., and as our engine is capable of exerting a tractive force of 22,000 lb., the total load which it can pull would be represented by

$$\frac{22{,}000}{39{\cdot}5}=556{\cdot}8 \text{ tons.}$$

As the engine and tender weigh about 72 tons, the train which our engine will pull will be represented by 556·8—72 =484·8 tons, which is equal to about 24 loaded cars. Of course, to do this work the cylinders must be large enough to turn the wheels, and the boiler have the requisite capacity to supply steam.

For the calculation of the size of the cylinders, there is only room here to give a simple rule, which is only

approximately correct, but near enough for ordinary purposes. This is: Multiply the total weight on the driving wheels in tons (of 2,000 lb.) by their diameter in inches; then four times the product will be the cubical capacity of one cylinder, or rather of the space swept through by the piston during a half revolution of the wheels. Having the cubical contents of the cylinder, the diameter can readily be found from the stroke, or the stroke from the diameter.—*Railroad Gazette.*

CHAPTER XXIII.

LOCOMOTIVE ENGINE RUNNING.*

HOW LOCOMOTIVE ENGINEERS ARE MADE — VARIOUS METHODS OF SELECTING MEN FOR THE RUNNING OF LOCOMOTIVES—SYSTEMS OF APPOINTING FIREMEN—KINDS OF EXAMINATION FIREMEN MUST PASS BEFORE BEING PROMOTED.

LOCOMOTIVE engine running is one of the most modern of trades, consequently its acquirement has not been controlled by the exact methods associated with ancient guild apprenticeships. Nevertheless, graduates to this business do not take charge of the iron horse without the full meed of experience and skill requisite for performing their duties successfully. The man who runs a locomotive engine on our crowded railroads has so much valuable property, directly and indirectly, under his care, so much of life and limb depending upon his skill and ability, that railroad companies are not likely to entrust the position to those with a suspicion of incompetency resting upon them.

The prevailing methods of raising locomotive engi-

* Angus Sinclair.

neers have been evolved from experience with the kind of men best adapted to fill the position. In the early days of the railroad world, when such men as George Stephenson, Horatio Allen, John B. Jervis, Ross Winans, and other pioneer engineers, demonstrated the successful operation of the locomotive, they usually turned over the care of their engines to the men who had assisted in constructing the machines, or in putting them together. This was the best that could be done at the time, and the men selected generally proved competent for the trust reposed in them; but it gave rise to a belief that no man could run a locomotive successfully unless he was a machinist. The possession of mechanical skill necessary for making repairs was considered the best recommendation for an engineer. Under this system, all that a machinist was required to do—so that he could graduate as a full-fledged engineer—was to practice moving engines round in the yard for a few days, when he was reported ready for the road. Akin with this sentiment was that which recommended youths, of natural mechanical ability, for the position of locomotive engineer, without subjecting them to any previous special training. Graduates from mechanical institutes were deemed capable of running an engine as soon as they were perfectly certain about how to start and stop the machine. The late Alexander L. Holley used to relate an anecdote of this kind of an engineer. During a severe winter storm, the train Holley was traveling on got firmly stalled in a snow-bank. In her struggles

with the frozen elements, the engine got short of water, and Holley found the engineer trying to fill the boiler by shoveling snow down the smoke-stack!

But it came to pass that more light in the matter of engine running dawned upon the minds of railroad managers. They discovered that expertness in effecting repairs on locomotives was not so essential in an engineer as was the less pretentious ability of working the engine so that the train would be pulled over the road safely and on time; they perceived but scanty merit in inherited mechanical genius, which did not inspire a youth with sagacity enough to see that certain destruction would befall the heating surface when he attempted to run without water in the boiler. Experience demonstrated that, to manage an engine on the road so that its best work should be developed at the least cost, certain traits of skill and training were necessary, which were altogether different from the culture that made a man smart at constructing or repairing machinery. It was found that one man might be a good machinist and yet make no kind of a decent runner; a second man would be equally expert in both capacities; while a third man who never could do a respectable job with tools, developed into an excellent engineer. One of the best millwrights I ever knew, a man who achieved considerable celebrity for skill in his craft, became a fireman with the ambition of becoming a locomotive runner. He fired acceptably for two years, then was promoted, but quickly found that he could not run an engine, and acknowledged that to be

the case by returning to the left side. He was too nervous, and lacked confidence in himself. Overweening egotism is not an attractive feature in a man's character, but, everything else being equal, it is the self-confident man that makes the successful engineer.

The experiment of raising locomotive engineers from machinists and mechanical empirics was the uncertain groping in the dark for the right man to fill the right place. When the search for pretentious men proved unsatisfactory, the right men were found at hand, accumulating the necessary experience on the firemen's side of the engine. Then it became a recognized fact, that to take hold and run an engine to advantage, a man must learn the business by working as fireman. There have been frequent cases of men becoming successful locomotive engineers without any previous training as firemen, but they were the exceptions that proved the rule.

In the matter of speed alone, there is much to learn before a man can safely run a locomotive. During daylight a novice will generally be half out in estimating speed, and his judgment is merely wild guesswork, regulated more by the condition of the track than by the velocity his train is reaching. On a smooth piece of track, he thinks he is making twenty-five miles an hour when forty miles is about the correct speed; then he strikes a rough portion of the road bed, and concludes he is tearing along at thirty miles an hour, when he is scarcely reaching twenty miles, since the first lurchy spot made him shut off twenty

per cent. of the steam. At night the case is much worse, especially when the weather proves unfavorable. On a wild, stormy night, the accumulated experience of years on the footboard, which trains a man to judge of speed by sound of the revolving wheels, and to locate his position between stations from a tree, a shrub, a protruding bank, or any other trifling object that would pass unnoticed by a less cultivated eye, is all needed to aid an engineer in working along with unvaried speed without jolt or tumult. On such a night, a man strange to the business cannot work a locomotive and exercise proper control over its movements. He may place the reverse lever-latch in a certain notch and keep the steam on; he can regulate the pump after a fashion, and watch that the water shall not get too low in the boiler; he can shut off in good season while approaching stations and blunder into each depot by repeatedly applying steam; but he exerts no control over the train, knows nothing of what the engine is doing, and is constantly liable to break the train in two. A diagram of his speed would fluctuate as irregularly as the profile lines of a bluffy country. This is where a machinist's skill does not apply to locomotive running until it is supplemented by an intimate knowledge of speed, of facility at handling a train and keeping the couplings intact, and of insight into the best methods of economizing steam.

These are essentials which every man should possess before he is put in charge of a locomotive on the road. The great fund of practical knowledge which

stamps the first-class engineer, is amassed by general labor during years of vigilant observation on the foot-board, amidst many changes of fair and foul weather.

As passing through the occupation of fireman was the only way men could obtain practical knowledge of engine running before taking charge, railroad officials all over the world gradually fell into the way of regarding that as the proper channel for men to traverse before reaching the right-hand side of the locomotive.

As the pay for firemen rules moderately good, even when compared with other skilled labor, and, as the higher position of engineer looms like a beacon not far ahead, there is always a liberal choice of good men to begin work as firemen. Most railroad companies recognize the importance of exercising judgment and discretion in selecting the men who are to run as their future engineers. Sobriety, industry and intelligence are essential attributes in a fireman who is going to prove a success in his calling. Lack in any one of these qualities will quickly prove fatal to a fireman's prospects of advancement. Sobriety is of the first importance, because a man who is not strictly temperate should not be tolerated for a moment about a locomotive, since he is a source of danger to himself and others; industry is needed to lighten the burden of a fireman's duties, for oftentimes they are arduous beyond the conception of strangers; and wanting in the third quality, intelligence, a man can never be a good fireman in the wide sense of the word, since one de-

ficient in mental tact never rises higher than a human machine. An intelligent fireman may be ignorant of the scientific nomenclature relating to combustion, but he will be perfectly familiar with all the practical phenomena connected with the economical generation of steam. Such a man does not imagine that he has reached the limit of locomotive knowledge when he understands how to keep an engine hot, and can shine up the jacket. Every trip reveals something new about his art, every day opens his vision to strange facts about the wonderful machine he is learning to manage. And so, week by week, he goes on his way, attending cheerfully to his duties, and accumulating the knowledge that will eventually make him a first-class locomotive engineer.

On the various roads throughout the North American Continent there is great diversity of practice in the selection of men for the position of firemen.

On numerous roads, especially in the Western States, men are taken from all occupations, no preliminary training being deemed necessary before putting a man on an engine as fireman. A list of applicants is kept by the master mechanic, and likely men recommended for firemen. When a man is wanted, the first one who can be found conveniently is sent out, and the engineer must break him in as best he can. On other roads, again, the men intended for firemen are taken to work about the round-house, and are employed in helping with the cleaning, repairing and preparing of locomotives for the road. This plan

is greatly in vogue in Europe, and on certain of the older roads of America, and it has many features to recommend it over the practice of placing men entirely devoid of railroad experience upon engines. It is better for the men themselves, since working about engines familiarizes them to some extent with the work they are expected to do as an engineer's helper, for that is really a fireman's position; it is better for the company, since the officers get the opportunity of observing a man's habits before his receiving training that entails some expense; it is better for the engineer, since his assistant is not entirely strange to the work he is expected to do. A youth entirely unacquainted with all the operations which a fireman is called upon to perform finds the first trip a terribly arduous ordeal, even with some previous experience of railroad work. When his first trip introduces him to the locomotive and to railroad life at the same time, the day is certain to be a record of personal tribulation. To ride for ten or twelve hours on an engine for the first time, standing on one's feet, and subject to the shaking motion, is intensely tiresome if a man has no work to do. But where he has to ride during that period, and in addition has to shovel six or eight tons of coal, most of which has to be handled twice, the job proves no sinecure. Then the posture of his body while doing work is new; he is expected and required to pitch coal on to certain exact spots, through a small door, while the engine is swinging about so that he can scarcely keep his feet; his hands get blistered with the shovel and

his eyes grow dazzled from the resplendent light of the fire. Then come the additional side duties of taking water, shaking the grates, cleaning the ash-pan, or even the fire, where but coal is used, filling oil-cans and trimming lamps, to say nothing of polishing and keeping things clean and tidy. By the time all these duties are attended to, the young fireman does not find a great deal of leisure to admire the passing scenery.

A great many idle young fellows, ignorant of railroad affairs, imagine that a fireman's principal work consists of ringing the bell, and showing himself off conspicuously coming into stations. They look upon the business as being of the heroic kind, and strive to get taken on as fireman. If a youth of this kind happens to succeed, and starts out on a run of one hundred and fifty miles with every car a heavy engine will pull stuck on behind, his visions of having reached something easy are quickly dispelled.

Like nearly every other occupation, that of fireman has its drawbacks to counterbalance its advantages; and the drawbacks weigh heaviest during the first ten days. The man who enters the business under the delusion that he can lead a life of semi-idleness must change his views or he will prove a failure; the man who becomes a fireman with a spirit ready and willing to overcome all difficulties, with a cheerful determination to do his duty with all his might, is certain of success, and to such a man the work becomes easy after a few weeks' practice.

Practice combined with intelligent observation gradually makes a man familiar with the best styles of firing, as adapted to all varieties of engines, and he gets to understand intimately all the qualities of coal to be met with, good, bad and indifferent. As his experience widens, his fire-management is regulated to accord with the kind of coal on hand, the steaming properties of the engine, the weight of the train, the character of the road and of the weather. Firing, with all the details connected with it, is the central figure of his work, the object of preëminent concern; but a good man does not allow this to prevent him from attending regularly and exactly to his remaining routine duties.

There is a familiar adage among railroad men, that a good fireman is certain to make a good engineer, and it rarely fails to come out true. To hear some firemen of three months' standing talk, a stranger might conclude that they knew more about engine running than the oldest engineer in the district. These are not the good firemen. Good firemen learn their own business with the humility born of earnestness, and they do not undertake to instruct others in matter beyond their own knowledge. It is the man who goes into the heart of a subject, who understands how much there is to learn, and is therefore modest in parading his own acquirements, that succeeds.

When a fireman has mastered his duties sufficiently to keep them going smoothly, he begins to find time for watching the operations of the engineer. He notes

how the boiler is fed, and upon his knowledge of the engineer's practice in this respect, much of his firing is regulated. The different methods of using the steam by engineers, so that trains can be taken over the road with the least expenditure of coal, is engraven upon the memory of the observant fireman. Many of the acquirements which commend a good firemen for promotion are learned by imperceptible degrees. The knowledge of speed, for instance, which enables a man to tell how fast a train is running on all kinds of track, and under all conditions of weather. There would be no use in one strange to train service going out for a few runs to learn speed. He might learn nearly all other requisites of engine running before he was able to judge within ten miles of how fast the train was going under adverse circumstances. The same may be said of the sound, which indicates how an engine is working. It requires an experienced ear to detect the false note which indicates that something is wrong. Amidst the mingled sounds produced by an engine and train hammering over a steel track, the novice hears nothing but a medley of confused noises, strange and meaningless as are the harmonies of an opera to an untutored savage. But the trained ear of an engineer can distinguish a strange sound amidst all the tumult of thundering exhaust, screaming steam and clashing steel, as readily as an accomplished musician can detect a false note. Upon this ability to detect the growing defects which pave the way to disaster, depends much of an engineer's chances of suc-

cess in his calling. This kind of skill is not obtained by a few weeks' industry; it is the gradual accumulation of months and years of patient labor.

I once knew a machine shop foreman, a man of extensive experience in building and repairing engines, take a locomotive out on a trial trip. A side rod pin began to run hot, and although he was leaning out of the cab window, he did not observe anything wrong till a drop of babbit struck him in the eye. An experienced engineer watching the rods would have detected the condition of affairs before babbit was thrown.

A difficult thing for an inexperienced man to control in running a locomotive at night, when the conditions for adhesion are bad, is the slipping of the drivers. Slipping is a simple matter enough to those who feel it in the vibrations of the engine; but the novice has not this sensitiveness to slipping vibration developed, and he must depend upon his eyesight or his hearing to detect it. On a dark stormy night the eye is useless as a means of judging as to the regularity of the revolving wheels; the howling wind or rain rattling on the cab drowns the sound of the exhaust. Under circumstances of this kind, an engine might jerk her pins out before the empirical engineer discovered she was slipping.

As his acquaintance with the handling and ordinary working of the locomotive extends, the aspiring fireman learns all about the packing of glands, and how they should be kept so as to run to the best advan-

tage; he displays an active interest in everything relating to lubrication, from the packing of a box cellar to the regulating of a rod cup. When the engineer is round keying up rods or doing other necessary work about his engine, the ambitious fireman should give a helping hand, and thereby become familiar with the operations that are likely to be of service when he is required to draw upon his own resources for doing the same work.

Of late years the art of locomotive construction has been so highly developed, the amount of strain and shocks to which each working part is subjected has been so well calculated and provided against, that breakages are really very rare on roads where the motive power is kept in first-class condition. Consequently, firemen gain comparatively small insight, on the road, into the best and quickest methods of disconnecting engines, or of fixing up mishaps promptly, so that a train may not be delayed longer than is absolutely necessary. A fireman must get this information beyond the daily routine of his experience. He must search for the knowledge among those competent to give it. Persistent inquiry among the men posted on these matters; observation amidst machine shop and round-house operations, and careful study of locomotive construction, so that a clear insight into the physiology of the machine may be obtained, will prepare one to meet accidents, armed with the knowledge which vanquishes all difficulties. Reflecting on probable or possible mishaps, and calculating what is

best to be done under all contingencies that can be conceived, prepare a man to act promptly when a break-down occurs.

CHAPTER XXIV

USEFUL NOTES.

STEEL AND STEEL MAKING.

THERE are two kinds of crucible steel, pot steel and cemented steel. The first, as its name indicates, is carbonized in the pot or crucible, and after being melted is cast into an ingot suited to the work in hand. It is thus made: A quantity of wrought-iron, steel scraps, powdered charcoal and flux are packed in a plumbago crucible, having a cover luted tight, and melted down, the quality of the iron and amount of charcoal and scrap determining the kind of steel made. Spring steel, for instance, being of a high grade of carbonization, requires more charcoal than tool-steel; while tool-steel, requiring great toughness, tenacity, and uniformity of quality, is made of a finer kind of iron, generally Swedes or Norway—of a special mark or brand. This is the system employed generally in American steel mills, and it has proven entirely satisfactory, so far as quality and quantity of production are concerned for a given capacity.

The other method of making crucible steel is indirect, as it is not carbonized in the pot, but by the cementation process. This is the oldest method in general use in civilized countries for carbonizing iron.

It consists, as most persons know, in subjecting wrought iron bars to a red heat for a certain time, confined in a receptacle and covered in with powdered charcoal, the carbon of which is absorbed, and the nature of the iron changed from fibrous to crystalline. These bars are then taken out and sorted, according to quality, and used as occasion requires. For example,—the steel, when taken from the box in which it is carbonized, is full of scabs or blisters, and is known as blistered steel. It is, of course, more or less imperfect. If these bars are cut and welded, it is known then as shear steel; shear steel, cut and rewelded, is known as double shear. To make crucible steel of cemented steel, the blister steel bars are broken up, sorted according to grade, and then melted in pots and cast in ingots; more or less wrought iron being added in the pot to the blister steel, to determine the quality desired to make.

It is easy to see, that by this process, very much more labor and expense are entailed than by the direct method, while it is questionable if any more accuracy of result is attained. Both systems have their advocates as regards fallibility, but being partisans of neither, we shall not discuss the matter here. We may say, however, in regard to the direct process, that it is the one practised by American steel makers (though some cemented steel is made by them also), and as our domestic steels have practically driven the English out of the market, the question seems to answer itself.

As shown in the foregoing paragraphs, these methods of making steel are, necessarily, expensive and slow, and the demands of civilization required less costly and swifter ones. The pressure resulted in the discovery of the product known as Bessemer steel. By this the steel is produced direct from cast iron, without the intermediate process of turning it into wrought iron. Briefly, cast iron, having too much carbon in it for steel-making, must first be deprived of it. This is accomplished by burning it out. To do this it is first melted and then run into large cast-iron vessels, lined with fire-brick, known as converters. In these it receives a blast of air, the oxygen of which combines with the excess of carbon and burns with an intense heat and brilliant flame. The iron, therefore, supplies its own fuel for its reduction. When the excess of carbon is consumed, the resulting iron is re-carbonized to the exact amount required, and the steel is made. It is then cast into ingots and is ready to be rolled at once.

This is the article known as Bessemer steel.

Siemens-Martin steel is also made in large masses, but, instead of using the pneumatic process described above, the charge is made, partially, of wrought iron and steel scrap, and is kept in a state of fusion, on an open hearth, until the carbon is added to the amount required. It is then treated as other steels are, so far as manipulation is concerned. It also can be made in large masses, forty tons being the usual charge, and very uniform in quality; but although occupying a

position midway between crucible and pneumatic steels, and being a formidable rival to the first, it has many peculiarities of nature which are not fully understood, and which prevent it from supplanting crucible steel in any work where cutting edges are required, such as axes and carpenters' tools generally. It is capable of being hardened, but not tempered, and there is a vast difference in these two stages. If Siemens-Martin steel is chilled, and the resulting hardness drawn, as in crucible steel, when a chisel is made the temper runs right down; the color shown is quite unlike crucible steel, being much duller and altogether different in aspect; while the condition of the cutting edge lacks durability. It seems to be more like case-hardening than tempering.

HEATING STEEL.

Much of the difficulty experienced by machinists in occasional attempts to forge their own tools comes from improperly heating the steel. To produce a good cutting tool, steel should be heated no more than is necessary to forge and temper. Follow the advice so frequently given to heat slowly, but at the same time avoid being too long in heating. The best results are obtained by a moderate, even heat, until the proper degree is reached, and then forging at once. It is a great but common mistake to allow the piece to come to the proper heat and then lie in the fire with the blast shut off for some minutes.

While this should not be done in the process of forging, the practice should be particularly guarded

against when heating to harden. In the process of forging the hammering in some degree seems to "restore" the steel; but when the tool is hardened and tempered from such a heat there is no possibility of its ever being of much use. In tempering the drawing should be done quite slowly, as in this way a much better cutting tool is produced than when it is rapidly performed.

The color is by no means a sure test of temper, since different kinds of steel do not take the same color for equal degrees of hardness. This is also true of steel that has been worked considerably, as old tools. The only guide in this respect is experience and judgment.

Steel for tools should never be heated, either for forging or tempering, in a fresh coal fire (unless it be charcoal).

If coke is not at hand the fire should be allowed to burn until the gas is burned out of the coal, before the steel is introduced. What has been said in reference to heating steel for cutting tools is equally applicable to steel used in making springs.

TO TEMPER STEEL.

Heat the steel slowly and turn it over often, so it will heat evenly; do not heat the steel over a good red heat. Plunge it in clear cold water. Be sure and hold it perpendicular, and don't move it sideways; by so doing it will cool evenly, and not be so apt to spring. For the most of tools it is best to keep it immersed in

the water until perfectly cold. Rub the tool with sandstone or other article that will give it a bright surface, so you can see the color. Heat an iron, and hold the tool on the iron until the color comes to a straw shade, then cool it so it will run no lower. The hardness indicated by the above shade is suitable for almost all kinds of turning tools for wood or metal. For cold chisels, let the color run lower, or to a light blue.

WATER ANNEALING.

Heat the steel to a red heat, and let it lie a few minutes, until nearly black hot; then throw it into soapsuds; steel in this way may be annealed softer than by putting it into the ashes of the forge.

MILD STEEL IN THE WORK-SHOPS.

The occasional failure of steel plates in boiler and other work, says the *Engineer and Iron Trades Advertiser*, is generally attributed to want of sufficient information on the part of the workmen. To prevent, as far as practicable, the possibility of failure in steel plates, caused by deficient information as to the proper method of treating this material, the Steel Company of Scotland has published and directs the attention of the users of the steel to the following rules:

"1. Welding: In welding mild steel plates, it is not necessary to heat them to the same high temperature as in the case of iron. Instead of a 'welding heat,' a bright yellow heat is sufficient; and if flux is required, it need only be three parts clean sand to one part common salt, moistened, and thrown on the parts in

the fire. We recommend that the weld be of the V form, in preference to the lap, and that it be treated in the usual way—that is, lightly hammered on the V part. After the weld is made, and while the heat is good, the parts near and on either side of the weld should also be lightly hammered. In making the weld, the fuel should be used free from sulphur, otherwise red shortness may result.

"2. Flanging: In flanging, care should be taken in the local heating that the parts are not overheated, and that no hammering or work is put upon them while at a black heat; further, it would be well if work could be continuous until each flange is completed, or, if the plate has to be laid aside before it is finished, it should be protected from chills, if it is not convenient to keep it warm.

"3. Annealing: After completing either welding or flanging, the whole piece should be heated to a cherry-red heat, and slowly cooled.

"4. Orders: In ordering steel plates care should be taken to state the purpose for which they are to be used, especially in cases where they are required to weld and flange."

STEEL BOILERS.

The substitution of steel for iron in steam boilers is one of the important mechanical improvements of the times. Steel is now made possessing the peculiar qualities needed in boiler shells with far greater durability than iron, and greater strength for resistance.

The expense of building steel boilers is but little more than that of first-class iron, while the additional security given is worth much larger outlays and efforts.

ANNEALING STEEL.

Annealing at a high heat is injurious. Annealing at a low heat can do no harm to steel which is to be hardened afterwards, and if applied to steel which has been heated too hot for either forging, annealing or hardening, will, to a great extent, restore such injured steel. *Heat low*, thereby keeping steel which is good all right, and making that which has been injured better.

HOW TO TEMPER A DRILL VERY HARD.

Heat your drill to a cherry-red and quench it in mercury. This will drill hardened steel.

GOOD TAPS AND DIES.

Nothing is more essential in a machine shop than good accurate taps and dies.

MAKING A TAP.

In making a tap, when it is necessary to file a clearance in the threads, it will be found of advantage to heat it until it becomes blue, before filing; the difference between that color and the newly-filed portions being an excellent guide in the filing. This will apply to reamers and many other tools.

TO TURN CHILLED IRON.

At Lister's Works, Darlington, England, some articles required turning in the lathe, and cast steel could

not be made hard enough to cut them. One man proposed cast metal tools. He was laughed at, of course, but his plan had to be tried. Well, cast metal tools were tried, with points chilled, and they cut when cast steel tools were of no use. The article was turned up with metal tools.

PLANING METALS.

The first operation about planing is to oil your planer and find out if the bed is smooth. If it is not, file off the rough places; then change the dogs to see if they will work well, and find out the movements of the planer. After doing this, bolt your work on the bed, and if it is a long, thin piece, plane off a chip, then turn it over and finish the other side, taking two chips, the last of which should be very light. Great care should be taken, in bolting it to the bed, not to spring it. After finishing this side, turn it to the other side, and take off a light cut to finish it.

DRILLING METALS.

In drilling brass, copper, lead, zinc, and solder, no oil should be used. Run the drill fast on brass, but slow on the other of these metals. In drilling wrought or cast iron run the drill slowly, using oil with the former but never with the latter. The drill should be well oiled in drilling cast steel; and a quarter inch drill should not run over 250 revolutions per minute. Twist drills are the best and most durable. Care should be taken to grind them perfectly true, for if one lip is longer than the other a larger hole will be drilled than is wanted.

QUALITIES OF LUBRICATING OILS FOR MACHINERY.

La Houille gives an interesting report, published by M. Ortolan, the chief engineer of the French navy, on the qualities of lubricating oils. It appears from that report that this gentleman has lately made some extensive investigations in the matter, and concludes with the advice how all lubricating oils for machinery should be tested: First equal parts by weight of soda and crystals are mixed; a small quantity of this solution is then put into a glass tube, and an equal quantity of the oil to be tested is added, after which the tube is turned over five or six times. If the oil is pure, it will detach itself in small brilliant globules; if, on the other hand, a curdy and sticky deposit is formed, it proves that the oil contains free fatty acids. The amount of acids is then ascertained by other means. The same gentleman has made some considerable experiments with the piston of an engine that had been but little used, and which was placed at his disposal to determine the action of different oils. One of the pistons was lubricated with olive oil, containing 7 per cent. of free acid; and a fellow piston with the same oil, neutralized and refined, and consequently free from acid. At the end of eight months, the piston which had been lubricated with the impure oil was covered by a dark brown grease, which adhered much to the metal. Analyzed, this proved to contain 6¼ per cent. of iron; the neutral oil had become yellow and a little thick, but did not contain a trace of iron. The same experiments repeated on other machines,

both in summer and winter, gave exactly the same results. The quality of the oil has naturally a great influence upon the power transmitted by the machine; thus, in a steam iron-clad, having engines indicating 4,500 horse-power, a bad oil *caused an extra consumption of four hundred weight of fuel per hour.* That the consumption of coal and that of oil are in inverse proportion is well understood in all large manufacturing districts, where great attention is paid, in certain mills turning much machinery, to the quality of the oil. All users of machinery can, therefore, not be too careful in having their oil analyzed, and the manner of doing so indicated above, which is both simple and handy, may, perhaps, induce many of our readers to adopt it, who have never thought of these tests before.

HOW TO FILE WORK IN THE VISE.

Few men that call themselves good workmen know how to file a piece of work in the vise. The most of them think that it is only necessary to run a file across the work in almost any shape to have it done right. It is a nice job to file a piece of work true. In the first place, you must have the work held firmly, and have the part to be filed horizontal. You must have a good handle, and have it put on the file straight. Hold the file firmly, and do not shove it too fast, nor bear down when you draw the file back. Be sure and run the file straight across the work. You cannot make a good job nor file the work straight if you bear down on the file hard. Many persons will raise one hand and lower the other every time they make a stroke. This is all

wrong, as the work will be round. You must keep the file clean, or the work will be scratched. If you wish to do a fine job, it will be found advantageous to oil the file or to chalk it; then the chips will not stick to the file.

POSITION AND INFLUENCE OF MASTER MECHANICS.

Upon taking the position of master mechanic of a railroad, one of the first questions that suggests itself to the mind of an individual is, *What rights and privileges am I entitled to, and to what extent can I exercise them in my position as master mechanic of this road?* This is an exceedingly difficult problem to solve, requiring much time and careful study, and in many cases it has never been solved. There was a time, years ago, when a master mechanic was, indeed, all that the title implies; he had exclusive control of the motive power department; but at the present day, in many cases, it is difficult to say whether the term *master mechanic* applies to the man, or whether it is merely the name of the position occupied by the man. We claim that the position of master mechanic should be filled by no one except a man who is really a master of his business; and when installed in the position of master mechanic of a railroad he should be allowed full charge of his department. Sufficient confidence should be reposed in him to give the assurance that matters would be managed for the interest of the company, and true economy studied in every particular.

The privileges and rights of a master mechanic today depend upon the influence that he can control;

also the influence and disposition of his superior officers. The very worst position in which he can be placed is where his superior officers understand little or nothing about motive power or mechanics, and yet will insist upon his following their directions. In fact, no alterations, repairs, or experiments are to be made without orders from them. When this state of affairs exists upon a railroad, the result is a disposition on the part of the master mechanic to do little more than is absolutely required. No improvements are made, and the result is a loss of thousands of dollars every year to the company. If the officers of the company are interviewed in regard to the management of the road, they will assert that they are running very economically.

We will give a few instances. A certain road was short of engines; a throttle gland was broken, and there were no castings on hand. The break was of such a nature that it could not be repaired, so a requisition was made stating the case and what was wanted, at once. The castings for this road were made and furnished on a contract by an outside concern, and no castings were allowed to be made in the shop. The result in this case was that the engine was delayed for two weeks, when it should have been out on the road within as many hours, had the master mechanic been allowed to have an extra gland in stock, or even to make a casting. Under the circumstances he was powerless to act, and therefore had to await the pleasure of his superiors. We may add that the company,

at the time of the above incident, valued each engine at $25 per day upon the road, while the actual cost of the gland finished was less than $2.

In another case some brass rivets were required for riveting a new boiler jacket. A requisition was made, and after a delay of one week the information came that there were no such rivets in the market, when it was well known that the necessary quantity of rivets could be bought for ten cents in any of the leading hardware stores. Some brass wire was ordered, a set of dies were made, and after making the necessary number of rivets the jacket was put together. Much satisfaction was afforded the master mechanic from the fact that before the engine left the shop a large box full of the rivets desired was received, being a sufficient quantity to last the company until their lease expires, which will be about ninety years hence.

A certain railroad company were persuaded to purchase the patent right to use a particular style of cast-iron packing rings, which after a while proved to be worthless. The master mechanic proposed to abandon the use of the rings, which proposition was met with a smile of derision by a superior officer, accompanied with the statement that the company had paid a large sum for the right to use the packing, and they were not going to abandon it. The result is that the cylinders on the locomotives are badly worn and cut, instances being quite common where the bottoms of the cylinders are worn 3-16ths of an inch below where they ought to be. When one of these engines was

working heavily, and an indicator was applied to the cylinder, it was discovered that there was a cloud of iron flying about inside the cylinder, causing the piston and cylinder of the indicator to be badly scratched. All this was discovered to be caused by the use of a badly-designed packing. We were present on one occasion when a cylinder head and follower were removed, and one of the packing rings was found broken into fifteen pieces. We counted them as they were taken out, and examined the bore of the cylinder, which strongly resembled the inside of a barrel.

Taking into consideration the wear and tear of the engine, loss of power through friction and leakage, the necessity of frequently boring the cylinders, and the unnecessary wear of the parts by getting out of line, it would be a difficult task to compute the total loss to the company, through the continuance of the use of a packing which they had been unfortunate enough to purchase.

If that master mechanic had been allowed to have his way, he would have abandoned the use of such packing at once, and adopted a style which would be cheap and economical.

We might recount many instances similar to those referred to, but they would not make the case any stronger. We consider these sufficient to show the necessity of allowing a master mechanic to control his own department. We are familiar with a railroad where a master mechanic cannot test a certain kind of oil; he cannot take on or discharge men; neither can he em-

ploy any apprentices—without a consultation with a superior. There are in the shop referred to certain apprentices who are relatives or friends of officials, and they neither work themselves nor allow the other boys to do so when they can prevent it. We have seen these young rascals stand up and defy the master mechanic to discharge them, as they would come back again. Such treatment is greatly humiliating and cutting, particularly to a sensitive man, and when these instances occur he wishes himself out of the country.

It is of the greatest importance to the company that the master mechanic be thoroughly instructed in his position, and the more he knows the better will he be enabled to discharge the duties of it, and the more carefully will the interests of the company be served.

To this end every reasonable means should be supplied for experiment, and opportunities afforded to visit other roads, in order to study the different methods of doing work. We remember a circumstance where the president of a railroad refused to allow the master mechanic to attend the conventions of the American Master Mechanics' Association, considering it a loss of time; besides, he thought it detrimental to the interests of his company to allow the master mechanics to get their heads so full of different ideas. It is, perhaps, unnecessary to add that improvements were seldom made upon the motive power of that road. Railroad officials should not expect to realize satisfactory results from every experiment, and admonish the experimenter for his seeming extravagance, but rather en-

courage him, and satisfactory results will surely follow carefully-conducted experiments.

We were recently informed by the representative of a large manufacturing concern, that in experimenting they found, as a fair average, if one experiment out of every twenty-five succeeded, they were well repaid for the expense of experimenting. If railroad officials would take occasion to investigate some of the statements herein set forth, they would find the means to increase their dividends by reducing their expenses.

ELEMENTS IN RAILROAD ECONOMY.

There seems to be a misapprehension on the part of some railroad officials, from the fact that they do not properly consider the necessity and economy of making repairs in a thoroughly first-class manner.

The thought does not once appear to enter their heads that the railroads are repairing their own machinery, and if the work is not done well they run a serious risk of having an accident. We heard the complaint made in a railroad shop, not long since, that too much new work was being placed upon the engines. More of the old work might have been used, and the cost of repairs reduced. This would seem to be a wrong view of economy, from the fact that the engines to which reference has been made were in want of a thorough overhauling. One of these engines went out on the road, where, after running a few trips, a rod strap was broken, the cause being the failure of a rod bolt. Another engine upon the same road broke a cross-head gib, which, getting caught in the end of the guides,

became jammed so as to bend the guides and the piston rod. The cause in this case was the breaking of a cast iron gib, which was allowed to wear too thin. The managers of that road still insist upon using cast iron gibs as being the cheapest. The use of cast iron gibs upon the cross-heads of passenger engines cannot be too strongly condemned, as being highly dangerous and hazardous to the lives of passengers. The first cost is truly less than composition, but when a cast iron gib, having no other support than its ends, becomes worn thin, it is sure to break, causing sufficient damage to furnish that engine at least with good composition.

Cast iron has been acknowledged for years to be unreliable where subjected to sudden and irregular strains, yet it has found its way into places upon the locomotive that ought to be filled by a much tougher and more reliable metal.

We have known side rods to be allowed to run upon locomotives after flaws were discovered in them, thereby running the risk of tearing off the side of the engine, breaking the crank pins, and killing the engineer. On one occasion an engineer upon starting a train from the station, noticed something was wrong, and stepping from his engine, observed that one of the side rods was gone, while the other had assumed a shape resembling "a dog's hind leg." A search was instituted for the lost rod, which, after a fruitless search, was given up. Singular to state, the rod has never been found to this day. The Pennsylvania railroad have an

established rule to remove the side rods from passenger engines after they have been in constant use three years, and replace them with new ones. The fact is that many railroad companies run their machinery until it breaks down, then scientifically reflect upon what they make out to be an unavoidable accident, when, in reality, it was the result of carelessness and neglect. We have a case in mind where an engineer reported several spokes broken in the main driving wheel of a passenger engine. The wheel was examined by the master mechanic, who declared it would run for some time yet. The engineer remonstrated, but all to no purpose, and one day the train was behind time, and a telegram announced that "No. 9" had broken a driving wheel and was helpless. The tire upon the broken wheel had burst, and all that was left of the wheel was the hub and two or three spokes. The tire had broken into five pieces, which, together with pieces of the wheels, had been hurled in all directions, completely divesting the right-hand side of the engine of rods, wheel covers, pipes, and a portion of the cab, and barely grazing the head of the engineer. This was reported to the directors as an unavoidable accident, when, in reality, it was expected by the engineer every day for several months before it happened. Cases are on record of cracked driving wheels running for years without giving way, but they are exceptional. Where there appears to be danger it should be remedied at once, and thus spare the company the humiliation of being sharply criticised by the press and the public,

besides being damaged far beyond the cost of necessary repairs, made in time.

Some master mechanics are continually altering the valves and nozzles of their engines, in order to make them steam better and work with greater economy, yet they neglect to insist upon taking proper care of the boilers. These are allowed to run for months, in some cases, without being washed out. Let a boiler become fouled by scale and mud, and enormous losses are sustained. For instance, the heat-conducting power of iron is about thirty times greater than compact scale, therefore, when the scale is allowed to attain any considerable thickness, a great deal of heat is lost.

This loss of heat, as will readily be seen, also reduces the capacity of a boiler.

As a rule, locomotive boilers have too many tubes located from $\frac{3}{8}''$ to $\frac{7}{16}''$ apart. Such boilers can use dirty or chemically impure water but a short time before the tubes become coated with scale, and the spaces intended for water become nearly, sometimes entirely, closed.

In one instance we observed the cleaning of a boiler that had been in use for five years, during which time the cylinder part had not been washed, because it was not accessible. The leg, however, had been washed about once every two months. When the tubes were removed, they were coated with scale about $\frac{3}{16}''$ to $\frac{1}{4}''$ thick, and there were two ash-cart loads of dirt taken from the tubes and cylinder part of the boiler. In view of the fact that the lower rows of tubes, say

up to the sixth row from the bottom, fill up with soot and dirt within a few days after the engine leaves the shop, the bottom four rows of tubes should be left out, and a good hand hole plate, 4″×6″, should be cut in the front flue sheet. A key should be used in place of a nut to tighten the plate, as a nut would soon corrode so as to be worthless, but a key can be readily loosened.

By leaving out the worthless tubes, greater space is allowed for dirt and scale to deposit without interfering with the heating surface, and, by putting a gallon or two of refined petroleum into the boiler occasionally, the tubes will be kept almost free from scale, which falls to the bottom in the shape of mud.

One master mechanic, we have noticed, now builds his boilers with ⅞″ water space between the tubes. The result is a saving in fuel and a great reduction in the first cost of the boilers.

The matters we have referred to are too often considered by railroad officials of small importance, and they are too apt to insist upon the work of repairing being done as rapidly and cheaply as possible, even as if they were working for outside parties.

It pays to do work well. In other words, the best material should be used where subjected to great or sudden strains. A fine finish, as well as all "gingerbread," is unnecessary. This is subject to the discretion of the parties in charge, who should endeavor to strike the happy medium between true economy and the extravagance of neglect, which is too often classed in the category of genuine economy.

A GLOSSARY

OF TERMS APPLIED TO THE DIFFERENT PARTS OF THE LOCOMOTIVE, AND THE USES OF THE SAME:

Ash-pan.

A box or tray beneath the furnace, used to catch the falling cinders and ashes.

Axle.

The revolving shaft to which the wheels are secured.

Blast-pipe.

A pipe, contracted at its mouth, used to discharge the waste (exhaust) steam from the cylinders, and to excite an artificial draft in the furnace.

Blow-cock.

A cock placed at the bottom of the boiler, used to empty the boiler of water.

Boiler.

The source of power; a vessel in which the steam is generated.

Box.

A bearing enclosing the journal of a revolving shaft. Boxes are generally called "brasses." When made in two pieces the lighter is called the cap or crown brass, when turned on the outside and fitted into a stand or frame, they are called a "bushing." They are generally lined with Babbitt, or other soft metal, to reduce friction.

Brake.

A block or strap applied to the rim of a wheel, used to check its motion and bring it to a stop.

Cam.

A pulley turning on a shaft out of its centre. When made round and encircled by a strap, and used to work the valves of a steam engine, it is called an eccentric. It is a substitute for a small crank.

Check-valve.

See Valve.

Cab.

The house used to protect the engineer and fireman from the weather.

Counter-balance.

A large block of metal secured between two or more arms of the driving wheels, to balance the momentum of the moving machinery connected with the wheels.

Connecting Rod.

A rod to communicate the pressure on the piston to the crank-pin.

Crank.

In outside cylinder engines, the crank is formed by a pin in the wheel called the crank pin. The crank converts the rectilineal motion of the piston into the rotary motion of the wheels.

Cross-head.

A block moving in guides, having one end of the piston rod attached to it, and also one end of the connecting-rod.

Cut-off Valve.

An additional valve—not indispensable, and seldom used on locomotives—to shut off or cut off the admission of steam to the cylinder when the piston has only completed a part of its stroke.

Cylinder.

A cylindrical vessel closed at its ends by covers or heads. Steam is admitted at each end alternately, to press upon a block called the piston. The piston is made to fit steam-tight by means of packing rings to the inner circumference of the cylinder, and the action of the steam keeps it in motion from one end of the cylinder to the other.

Damper.

A door, used to exclude air from the furnace.

Dome.

An elevated chamber on top of the boiler, from which steam is taken to the cylinders.

Driving Wheels.

Those wheels turned directly by the moving machinery of the engine, and which, by their adhesion to the rails, propel the engine along.

Eccentrics.

See Cam.

Eduction Port.

Usually called "exhaust port." A passage on the side of the cylinder to lead away the waste (exhaust) steam from the same to the blast pipe.

Equalizing Lever.

A bar suspended by its centre beneath the frame, and connected at each end to the springs of the driving wheels; used to distribute any shock or jolt between both pairs of wheels.

Fire-Box.

The furnace of a boiler.

Foaming.

An artificial excitement, or too great ebullition of the water level, caused by too much water, greasy or dirty water, or malformation of the boiler. When foaming takes place the water in the glass gauge is violently agitated, and the gauge cocks show a frothy mixture—neither clear steam nor solid water.

Foot-Board.

A plate iron floor behind the boiler in the cab, upon which the engineer and fireman stand.

Frame.

Made to attach to the boiler, cylinders, axles, and all cross shafts. Used to bind the whole fabric together.

Glass Gauge.

A thick glass tube attached to the boiler, to show the height of the water in the boiler.

Gauge Cocks.

Small cocks inserted in the boiler at different levels to show the height of water, same as the glass gauge. When opened, water or steam will escape, according as the level of the water is above or below them

Gland.

A bushing to secure the packing in a stuffing-box.

Grate.

The bars supporting the fuel in the furnace.

Guides.

Rods or bars lying in the direction of the axis of the cylinder. Used for guiding the cross-head to insure a perfectly parallel motion in the piston rod.

Induction Ports.

Generally called steam ports. Two passages on top of the cylinder to admit steam within it—one port to each end.

Journal.

The part of a shaft or axle resting in a box.

Lagging.

A wooden sheathing around a boiler or cylinder, to prevent the radiation of heat.

Lap.

The distance which the valve overlaps on each end over the induction or steam ports, when in the middle of its travel.

Lead.

The distance which the steam port is opened when the piston begins its stroke.

Link Motion.

An arrangement for working the valves, fully described in the body of this book.

Man-hole.

A hole to admit a man within the boiler for cleaning or repairs.

Mud-holes.

Usually called "hand-holes." Small openings at the bottom of the water space around the fire-box. Used to clean out the mud and other deposits from the water.

Packing.

Any substance used to make a joint steam or water tight.

Piston.

See Cylinder.

Piston Rod.

A rod secured at one end within the body of the piston, and at the other to the cross-head. This rod passes through the cylinder cover, and is made steam-tight by packing secured in a recess outside of the cover called a stuffing-box.

Plug.

A lead plug tapped in top sheet of furnace to melt and give warning when water falls below it.

Plunger.

The solid piston of a pump, pressing only by one end against the water.

Ports.

Passages or openings for the entrance and exit of steam to and from the cylinders.

Priming.

Usually called foaming. The passage of water or foam along with the steam into the cylinders when the engine is working.

Reverse-bar.

A lever in the cab with which the engineer raises or lowers the link and valve-gear, and thereby controls the direction of the engine's motion.

Safety-valve.

A valve on the boiler to discharge the surplus steam generated above the working pressure, which, by accumulating, would endanger the safety of the boiler.

Smoke-box.

A chamber at the forward end of the boiler, where the smoke, etc., from the tubes is received and discharged through the chimney.

Steam Chest.

A box on top or side of the cylinder containing the valve for admitting steam to the cylinder.

Steam Pipe.

A pipe entering the dome and communicating with the steam chests through two branch steam pipes in the smoke box. Used to convey steam from the boiler to the cylinders.

Stuffing Box.

See piston rod. Used in all situations where a rod, having any end motion, requires to be made steam or water tight around the same.

Stroke.

The distance traveled by the piston at each end of its motion.

Tender.

A separate carriage attached to the engine, used to carry wood and water.

Throttle Valve.

A valve in the dome, and closing the mouth of the steam pipe.

Truck Frame.

A separate frame, supported by four or six wheels, which turns on a spindle independent of the body of the engine or car.

Tubes.

Tubes are used to conduct the products of combustion from the fire-box through the waist of the boiler to the smoke-box. When a tube is so large as to require to be made of plates riveted together, it is called a flue.

Valve.

Any fixture, other than a cock, to close a steam or water passage about an engine. A check valve is a valve used to prevent the water returning from the boiler to the pump.

APPENDIX.

TABLE OF TIME

Occupied in running One Mile, Speed in Feet per Minute, and Number of Revolutions of the Driving Wheels, or Double Strokes of the Piston, per Minute, at the following given speeds:

Speed per Hour.	Speed per Minute.	Time of running 1 mile.	Revolution of Wheels, per Minute—the Diameter of Wheels being in Feet.										
			3 feet.	3½ ft.	4 feet.	4½ feet.	5 feet.	5½ feet.	6 feet.	6½ feet.	7 ft.	7½ feet.	8 feet.
Miles.	Feet.	Min. Sec.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.
10	880	6 00	93.37	80	70.	62.25	56.02	50.93	46.68	43.09	40	37.35	35.01
11	968	5 27	102.71	88	77.	68.47	61.62	56.02	51.35	47.40	44	41.08	38.51
12	1056	5 00	112.04	96	84.	74.70	67.23	61.12	56.02	51.71	48	44.82	42.02
13	1144	4 37	121.37	104	91.	80.92	72.73	66.21	60.69	56.02	52	48.55	45.52
14	1232	4 17	130.70	112	98.	87.14	78.33	71.30	65.36	60.33	56	52.29	49.
15	1320	4 00	140.06	120	105.	93.37	84.03	76.40	70.03	64.64	60	56.02	52.53
16	1408	3 45	149.39	128	112.	99.69	89.63	81.50	77.70	68.93	64	59.76	56.
17	1496	3 32	158.72	136	119.	105.82	95.23	86.59	79.37	73.26	68	63.49	59.5
18	1584	3 20	169.06	144	126.	112.04	100.84	91.68	84.03	77.57	72	67.23	63.
19	1672	3 09½	178.39	152	133.	118.26	106.44	96.77	88.70	81.88	76	70.96	66.5
20	1760	3 00	187.72	160	140.	124.48	112.04	101.86	93.37	86.19	80	74.70	70.
21	1848	2 51½	197.05	168	147.	130.72	117.65	106.95	98.04	90.50	84	78.43	73.5
22	1936	2 43½	206.38	176	154.	136.94	123.25	112.04	102.71	94.81	88	82.17	77.
23	2024	2 36½	215 71	184	161.	143.17	128.85	117.14	107.38	99.12	92	85.50	80.5
24	2112	2 30	225.05	192	168.	149.40	134.45	122.24	112.95	103.43	96	89.63	84.
25	2200	2 24	233.48	200	175.	155.63	140.05	127.33	116.72	107.74	100	93.37	87.5
26	2288	2 18⅔	242.77	208	182.	161.85	145.65	132.42	121.39	112.05	104	97.14	91.
27	2376	2 13⅓	255.74	216	189.	168.07	151.26	137.52	126.05	116.36	108	100.87	94.5
28	2464	2 08⅓	261.43	224	196.	174.3	156.86	142.63	130.72	120.67	112	104.57	98.
29	2552	2 04	270.78	232	203.	180.52	162.47	147.74	135.38	124.98	116	108.32	101.5
30	2640	2 00	280.11	240	210.	186.74	168.08	152.85	140.04	129.30	120	112.02	105.
31	2728	1 56	289.52	248	217.	192.97	173.78	157.98	144.71	133.61	124	115.75	108.5
32	2816	1 52½	298.79	256	224.	199.20	179.39	163.	149.38	137.62	128	119.5	112.
33	2904	1 49	308.12	264	231.	205.42	185.	168.1	154.05	141.93	132	123.23	115.5
34	2992	1 45⅝	317.46	272	238.	211.64	190.60	172.99	158.72	146.24	136	127.06	119.
35	3080	1 42⅝	326.80	280	245.	217.13	196.21	177.29	163.33	150.85	140	130.69	122.5
36	3168	1 40	336.13	288	252.	224.09	201.82	182.4	168.	155.16	144	134.42	126.
37	3256	1 37¼	345.47	296	259.	230.32	207.42	187.5	172.67	159.41	148	138.16	129.5
38	3344	1 34¼	354.81	304	266.	236.54	213.03	192.6	177.34	163.72	152	143.90	133.
39	3432	1 32⅓	364.15	312	273.	242.77	218.63	197.95	182.05	168.03	156	145.63	136.5
40	3520	1 30	373 57	320	280,	252.72	224.24	203.76	186.72	172.40	160	149.36	140.
42	3696	1 25¾	392.15	336	294.	261.44	235.44	214.	196.05	181.02	168	156.83	147.
45	3960	1 20	420.17	360	315.	284.30	252.27	229.23	210.06	193.95	180	168.03	157.5
48	4224	1 15	438.18	384	336.	298.79	269.10	244.55	224.06	206.88	192	179.23	168.
50	4400	1 12	446.85	400	350.	315.90	280.30	254.75	233.70	215.50	200	186.70	185.
55	4840	1 05½	513.54	440	385.	347.49	308.33	280.17	256.74	237.05	220	205.37	192.5
60	5280	1 00	560.23	480	420.	379.08	336.36	305.64	280.5	258.6	240	224.04	210.1
65	5720	0 55⅓	606.91	520	455.	416.67	364.39	331.11	303.42	280.15	260	242.71	227.5
70	6160	0 51⅜	653.59	560	490.	442.19	392.42	356.58	326.76	301.70	280	261.38	245.
75	6600	0 48	700.28	600	525.	473.85	420.50	372.05	350.1	323.25	300	280.05	262.5
80	7040	0 45	746.96	640	560.	505.50	448.48	407.60	373.44	344.80	320	298.72	280.
85	7480	0 42⅓	792.74	680	595.2	528.38	476.50	433.25	396.77	346.35	340	317.42	297.5
90	7920	0 40	840.34	720	630.27	560.23	504.62	458.65	420.11	367.90	360	336.	315.14

Algebraic Signs as applied in Mechanical Calculations.

=Sign of equality, and signifies equal to, as 2 added to 5=7.
+Sign of addition, and signifies plus or more, as 4+2=6.
−Sign of subtraction, and signifies minus or less, as 7−5 =2.
×Sign of multiplication, and signifies multiplied by, as 7×6 =42.
÷Sign of division, and signifies divided by, as 20÷5=4.
√Sign of square root, ∛Sign of cube root } evolution, or the extraction of roots, thus √81=9 ∛729 =9.

Fractions of a foot in Inches.	Decimal Value in Feet.	Area in Feet.	Circumference in feet.	Fractions of an Inch.	Decimal Value.	Fractions of an Inch.	Decimal Value.
11	.9166	.6598	2.879	1/2 & 3/32	.96875	1/2 & 3/32	.46875
10	.8333	.54537	2.617	1/2 & 1/16 1/32	.9375	1/2 & 1/16 1/32	.4375
9	.75	.44178	2.356	1/2 & 1/32	.90625	1/2 & 1/32	.40625
8	.6666	.33779	2.094	1/2	.875	3/8 & 3/32	.375
7	.5833	.26722	1.832	3/4 & 3/32 1/16 1/32	.84375	1/4 & 3/32 1/16 1/32	.34375
6	.5	.19635	1.57	3/4 & 1/16 1/32	.8125	1/4 & 1/16 1/32	.3125
5	.4166	.1363	1.308	3/4 & 1/32	.78125	1/4 & 1/32	.28125
4	.3333	.08724	1.047	3/4	.75	1/4	.25
3	.25	.04908	.7854	5/8 & 3/32 1/16 1/32	.71875	1/8 & 3/32 1/16 1/32	.21875
2	.1666	.02179	.5233	5/8 & 1/16 1/32	.6875	1/8 & 1/16 1/32	.1875
1	.0833	.00544	.2616	5/8 & 1/32	.65625	1/8 & 1/32	.15625
7/8	.07291	.00417	.22907	5/8	.625	1/8	.125
3/4	.0625	.00306	.19635	1/2 & 3/32 1/16 1/32	.59375	3/32 1/16 1/32	.09375
5/8	.0520	.0028	.16362	1/2 & 1/16 1/32	.5625	1/16 1/32	.0625
1/2	.04166	.00136	.130899	1/2 & 1/32	.53125	1/32	.03125
3/8	.03125	.00076	.098174	1/2	.5		
1/4	.02083	.00035	.06545				
1/8	.01041	.000085	.032719				

A Table of Diameters, Areas, and Circumferences of Circles, from $\frac{1}{16}$ of an Inch to 110 Inches.

Dia.	Area.	Circum.	Dia.	Area.	Circum.
$\frac{1}{16}$	.0030	.1963	$\frac{5}{16}$	4.2001	7.2649
$\frac{1}{8}$	.0122	.3927	$\frac{3}{8}$	4.4302	7.4613
$\frac{3}{16}$	.0276	.5890	$\frac{7}{16}$	4.6664	7.6576
$\frac{1}{4}$	.0490	.7854	$\frac{1}{2}$	4.9087	7.8540
$\frac{5}{16}$	.0767	.9817	$\frac{9}{16}$	5.1573	8.0503
$\frac{3}{8}$	.1104	1.1781	$\frac{5}{8}$	5.4119	8.2467
$\frac{7}{16}$	.1503	1.3744	$\frac{11}{16}$	5.6727	8.4430
$\frac{1}{2}$	.1963	1.5708	$\frac{3}{4}$	5.9395	8.6394
$\frac{9}{16}$	.2485	1.7671	$\frac{13}{16}$	6.2126	8.8357
$\frac{5}{8}$	.3068	1.9635	$\frac{7}{8}$	6.4918	9.0321
$\frac{11}{16}$	.3712	2.1598	$\frac{15}{16}$	6.7772	9.2284
$\frac{3}{4}$	.4417	2.3562			
$\frac{13}{16}$	.5185	2.5525	3 in.	7.0686	9.4248
$\frac{7}{8}$	.6013	2.7489	$\frac{1}{16}$	7.3662	9.6211
$\frac{15}{16}$	.6903	2.9452	$\frac{1}{8}$	7.6699	9.8175
			$\frac{3}{16}$	7.9798	10.0138
1 in.	.7854	3.1416	$\frac{1}{4}$	8.2957	10.2102
$\frac{1}{16}$	.8861	3.3379	$\frac{5}{16}$	8.6179	10.4065
$\frac{1}{8}$	.9940	3.5343	$\frac{3}{8}$	8.9462	10.6029
$\frac{3}{16}$	1.1075	3.7306	$\frac{7}{16}$	9.2806	10.7992
$\frac{1}{4}$	1.2271	3.9270	$\frac{1}{2}$	9.6211	10.9956
$\frac{5}{16}$	1.3529	4.1233	$\frac{9}{16}$	9.9678	11.1919
$\frac{3}{8}$	1.4848	4.3197	$\frac{5}{8}$	10.3206	11.3883
$\frac{7}{16}$	1.6229	4.5160	$\frac{11}{16}$	10.6796	11.5846
$\frac{1}{2}$	1.7671	4.7124	$\frac{3}{4}$	11.0446	11.7810
$\frac{9}{16}$	1.9175	4.9087	$\frac{13}{16}$	11.4159	11.9773
$\frac{5}{8}$	2.0739	5.1051	$\frac{7}{8}$	11.7932	12.1737
$\frac{11}{16}$	2.2365	5.3014	$\frac{15}{16}$	12.1768	12.3700
$\frac{3}{4}$	2.4052	5.4978			
$\frac{13}{16}$	2.5801	5.6941	4 in.	12.5664	12.5664
$\frac{7}{8}$	2.7611	5.8905	$\frac{1}{16}$	12.9622	12.7627
$\frac{15}{16}$	2.9483	6.0868	$\frac{1}{8}$	13.3640	12.9591
			$\frac{3}{16}$	13.7721	13.1554
2 in.	3.1416	6.2832	$\frac{1}{4}$	14.1862	13.3518
$\frac{1}{16}$	3.3411	6.4795	$\frac{5}{16}$	14.6066	13.5481
$\frac{1}{8}$	3.5465	6.6759	$\frac{3}{8}$	15.0331	13.7445
$\frac{3}{16}$	3.7582	6.8722	$\frac{7}{16}$	15.4657	13.9408
$\frac{1}{4}$	3.9760	7.0686	$\frac{1}{2}$	15.9043	14.1372

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
9/16	16.3492	14.3335	7 in.	38.4846	21.9912
5/8	16.8001	14.5299	1/16	39.1749	22.1875
11/16	17.2573	14.7262	1/8	39.8713	22.3839
3/4	17.7205	14.9226	3/16	40.5469	22.5802
13/16	18.1900	15.1189	1/4	41.2825	22.7766
7/8	18.6655	15.3153	5/16	41.9974	22.9729
15/16	19.1472	15.5716	3/8	42.7184	23.1693
			7/16	43.4455	23.3656
5 in.	19.6350	15.7080	1/2	44.1787	23.5620
1/16	20.1290	15.9043	9/16	44.9181	23.7583
1/8	20.6290	16.1007	5/8	45.6636	23.9547
3/16	21.1252	16.2970	11/16	46.4153	24.1510
1/4	21.6475	16.4934	3/4	47.1730	24.3474
5/16	22.1661	16.6897	13/16	47.9370	24.5437
3/8	22.6907	16.8861	7/8	48.7070	24.7401
7/16	23.2215	17.0824	15/16	49.4833	24.9364
1/2	23.7583	17.2788			
9/16	24.3014	17.4751	8 in.	50.2656	25.1328
5/8	24.8505	17.6715	1/16	51.0541	25.3291
11/16	25.4058	17.8678	1/8	51.8486	25.5255
3/4	25.9672	18.0642	3/16	52.8994	25.7218
13/16	26.5348	18.2605	1/4	53.4562	25.9182
7/8	27.1085	18.4569	5/16	54.2748	26.1145
15/16	27.6884	18.6532	3/8	55.0885	26.3109
			7/16	55.9138	26.5072
6 in.	28.2744	18.8496	1/2	56.7451	26.7036
1/16	28.8665	19.0459	9/16	57.5887	26.8999
1/8	29.4647	19.2423	5/8	58.4264	27.0963
3/16	30.0798	19.4386	11/16	59.7762	27.2926
1/4	30.6796	19.6350	3/4	60.1321	27.4890
5/16	31.2964	19.8313	13/16	60.9943	27.6853
3/8	31.9192	20.0277	7/8	61.8625	27.8817
7/16	32.5481	20.2240	15/16	62.7369	28.0780
1/2	33.1831	20.4204			
9/16	33.8244	20.6167	9 in.	63.6174	28.2744
5/8	34.4717	20.8131	1/16	64.5041	28.4707
11/16	35.1252	21.0094	1/8	65.3968	28.6671
3/4	35.7847	21.2058	3/16	66.2957	28.8634
13/16	36.4505	21.4021	1/4	67.2007	29.0598
7/8	37.1224	21.5985	5/16	68.1120	29.2561
15/16	37.8005	21.7948	3/8	69.0293	29.4525
			7/16	69.9528	29.6488

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	70.8823	29.8452	12 in.	113.0976	37.6992
9/16	71.8181	30.0415	1/16	114.2788	37.8955
5/8	72.7599	30.2379	1/8	115.4660	38.0919
11/16	73.7079	30.4342	3/16	116.6645	38.2882
3/4	74.6620	30.6306	1/4	117.8590	38.4846
13/16	75.6223	30.8269	5/16	119.0648	38.6809
7/8	76.5887	31.0233	3/8	120.2766	38.8773
15/16	77.5613	31.2196	7/16	121.4946	39.0736
			1/2	122.7187	39.2700
10 in.	78.5400	31.4160	9/16	123.9490	39.4663
1/16	79.5248	31.6123	5/8	125.1854	39.6627
1/8	80.5157	31.8087	11/16	126.4479	39.8590
3/16	81.5128	32.0050	3/4	127.6765	40.0554
1/4	82.5160	32.2014	13/16	128.8999	40.2517
5/16	83.5254	32.3977	7/8	130.1923	40.4481
3/8	84.5409	32.5941	15/16	131.4279	40.6444
7/16	85.5626	32.7904			
1/2	86.5903	32.9868	13 in.	132.7326	40.8408
9/16	87.6243	33.1831	1/16	134.0120	41.0371
5/8	88.6643	33.3795	1/8	135.2974	41.2338
11/16	89.7105	33.5758	3/16	136.5890	41.4298
3/4	90.7627	33.7722	1/4	137.8867	41.6262
13/16	91.8212	33.9685	5/16	139.1907	41.8225
7/8	92.8858	34.1649	3/8	140.5007	42.0189
15/16	93.9566	34.3612	7/16	141.8169	42.2152
			1/2	143.1391	42.4116
11 in.	95.0334	34.5596	9/16	144.4726	42.6079
1/16	96.1164	34.7539	5/8	145.8021	42.8043
1/8	97.2053	34.9503	11/16	147.1428	43.0006
3/16	98.3008	35.1466	3/4	148.4896	43.1970
1/4	99.4021	35.3430	13/16	149.8426	43.3933
5/16	100.5097	35.5393	7/8	151.2017	43.5897
3/8	101.6234	35.7357	15/16	152.5670	43.7860
7/16	102.7432	35.9320			
1/2	103.8691	36.1284	14 in.	153.9384	43.9824
9/16	105.0012	36.3247	1/16	155.3159	44.1787
5/8	106.1394	36.5211	1/8	156.6995	44.3751
11/16	107.2838	36.7174	3/16	158.0893	44.5714
3/4	108.4342	36.9138	1/4	159.4852	44.7676
13/16	109.5909	37.1101	5/16	160.8374	44.9641
7/8	110.7536	37.3065	3/8	162.2956	45.1605
15/16	111.9226	37.5028	7/16	163.7099	45.3568

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	165.1303	45.5532	17 in.	226.9806	53.4072
9/16	166.5569	45.7495	1/16	228.6527	53.6035
5/8	167.9896	45.9459	1/8	230.3308	53.7999
11/16	169.4285	46.1422	3/16	232.0151	53.9962
3/4	170.8735	46.3386	1/4	233.7055	54.1926
13/16	172.3247	46.5349	5/16	235.4022	54.3889
7/8	173.7820	46.7313	3/8	237.1049	54.5853
15/16	175.2455	46.9276	7/16	238.8138	54.7816
			1/2	240.5287	54.9780
15 in.	176.7150	47.1240	9/16	242.2499	55.1743
1/16	178.1907	47.3203	5/8	243.9771	55.3707
1/8	179.6725	47.5167	11/16	245.7105	55.5670
3/16	181.1105	47.7130	3/4	247.4500	55.7634
1/4	182.6545	47.9094	13/16	249.1952	55.9597
5/16	184.1548	48.1057	7/8	250.9475	56.1561
3/8	185.6612	48.3021	15/16	252.7050	56.3524
7/16	187.1737	48.4984			
1/2	188.6923	48.6948	18 in.	254.4696	56.5488
9/16	190.2171	48.8911	1/16	256.2398	56.7451
5/8	191.7480	49.0875	1/8	258.0161	56.9415
11/16	193.3351	49.2838	3/16	259.7986	57.1378
3/4	194.8282	49.4802	1/4	261.5872	57.3342
13/16	196.3776	49.6765	5/16	263.3820	57.5305
7/8	197.9330	49.8729	3/8	265.1829	57.7269
15/16	199.4947	50.0692	7/16	266.9900	57.9282
			1/2	268.8031	58.1196
16 in.	201.0624	50.2656	9/16	270.6225	58.2159
1/16	202.6363	50.4619	5/8	272.4479	58.5123
1/8	204.2162	50.6583	11/16	274.2895	58.7806
3/16	205.8024	50.8546	3/4	276.1171	58.9056
1/4	207.3946	51.0510	13/16	277.9610	59.1013
5/16	208.9931	51.2473	7/8	279.8110	59.2977
3/8	210.5976	51.4437	15/16	281.1672	59.4940
7/16	212.2083	51.6400			
1/2	213.8251	51.8364	19 in.	283.5294	59.6904
9/16	215.4481	52.0327	1/16	285.3978	59.8867
5/8	217.0772	52.2291	1/8	287.2723	60.0831
11/16	218.7124	52.4254	3/16	289.4030	60.2794
3/4	220.3537	52.6218	1/4	291.0397	60.4758
13/16	222.0013	52.8181	5/16	292.9324	60.6721
7/8	223.6549	53.0145	3/8	294.8312	60.8685
15/16	225.3147	53.2108	7/16	296.7367	61.0648

DIAMETERS, AREAS, ETC.— *Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	298.6483	61.2612	22 in.	380.1336	69.1152
9/16	300.5658	61.4575	1/16	382.2965	69.3115
5/8	302.4894	61.6539	1/8	384.4655	69.5079
11/16	304.4192	61.8502	3/16	386.6907	69.7042
3/4	306.3550	62.0466	1/4	388.8220	69.9006
13/16	308.2971	62.2429	5/16	391.0095	70.0969
7/8	310.2452	62.4393	3/8	393.2031	70.2933
15/16	312.1996	62.6356	7/16	395.4029	70.4806
			1/2	397.6087	70.6860
20 in.	314.1600	62.8320	9/16	399.8207	70.8823
1/16	316.1266	63.0283	5/8	402.0388	71.0787
1/8	318.0992	63.2247	11/16	404.2631	71.2750
3/16	320.0781	63.4210	3/4	406.4935	71.4714
1/4	322.0630	63.6174	13/16	408.7301	71.6677
5/16	324.0542	63.8137	7/8	410.9728	71.8641
3/8	326.0514	64.0101	15/16	413.2317	72.0604
7/16	328.0548	64.2064			
1/2	330.0643	64.4028	23 in.	415.4766	72.2568
9/16	332.0800	64.5991	1/16	417.7377	72.4531
5/8	334.1018	64.7955	1/8	420.0049	72.6495
11/16	336.1297	64.9918	3/16	422.2783	72.8458
3/4	338.1637	65.1882	1/4	424.5577	73.0422
13/16	340.2040	65.3845	5/16	426.3434	73.2385
7/8	342.2502	65.5809	3/8	429.1352	73.4349
15/16	344.3028	65.7772	7/16	431.4331	73.6312
			1/2	433.7371	73.8276
21 in.	346.3614	65.7936	9/16	436.0473	74.0239
1/16	348.4267	66.1699	5/8	438.3636	74.2203
1/8	350.4970	66.3663	11/16	440.6811	74.4166
3/16	352.5740	66.5626	3/4	443.0146	74.6130
1/4	354.6571	66.7590	13/16	445.3539	74.8093
5/16	356.7465	66.9553	7/8	447.6992	75.0057
3/8	358.8419	67.1517	15/16	450.0418	75.2020
7/16	360.9435	67.3480			
1/2	363.0511	67.5444	24 in.	452.3904	75.3984
9/16	365.1650	67.7407	1/16	454.7497	75.5947
5/8	367.2849	67.9371	1/8	457.1150	75.7911
11/16	369.4110	68.1334	3/16	459.4866	75.9874
3/4	371.5432	68.3298	1/4	461.8642	76.1838
13/16	373.6816	68.5261	5/16	464.2481	76.3801
7/8	375.8261	68.7225	3/8	466.6380	76.5765
15/16	377.9768	68.9188	7/16	469.0341	76.7728

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	471.4363	76.9692	27 in.	572.5566	84.8232
9/16	473.8447	77.1655	1/16	575.2104	85.0195
5/8	476.2592	77.3619	1/8	577.8703	85.2159
1 1/16	478.6798	77.5582	3/16	580.5364	85.4122
3/4	481.1065	77.7546	1/4	583.2085	85.6086
1 3/16	483.5395	77.9509	5/16	585.8869	85.8049
7/8	485.9785	78.1473	3/8	588.5714	86.0013
1 5/16	488.4237	78.3436	7/16	591.2620	86.1976
			1/2	593.9587	86.3940
25 in.	490.8750	78.5400	9/16	596.6616	86.5903
1/16	493.3325	78.7363	5/8	599.3706	86.7867
1/8	495.7960	78.9327	1 1/16	602.0858	86.9830
3/16	498.2657	79.1290	3/4	604.8070	87.1794
1/4	500.7415	79.3254	1 3/16	607.5345	87.3757
5/16	503.2236	79.5217	7/8	610.2680	87.5721
3/8	505.7117	79.7181	1 5/16	613.0078	87.7684
7/16	508.2060	79.9144			
1/2	510.7063	80.1108	28 in.	615.7536	87.9648
9/16	513.2129	80.3071	1/16	618.5051	88.1611
5/8	515.7255	80.5035	1/8	621.2636	88.3575
1 1/16	518.2443	80.6998	3/16	624.0279	88.5538
3/4	520.7692	80.8962	1/4	626.7982	88.7502
1 3/16	523.3003	81.0925	5/16	629.5748	88.9465
7/8	525.8375	81.2889	3/8	632.3574	89.1429
1 5/16	528.3809	81.4852	7/16	635.1462	89.3392
			1/2	637.9411	89.5356
26 in.	530.9304	81.6816	9/16	640.7422	89.7319
1/16	533.4860	81.8779	5/8	643.5494	89.9283
1/8	536.0477	82.0743	1 1/16	646.3627	90.1246
3/16	538.6156	82.2706	3/4	649.1821	90.3210
1/4	541.1896	82.4670	1 3/16	652.0078	90.5173
5/16	543.7698	82.6633	7/8	654.8395	90.7137
3/8	546.3561	82.8597	1 5/16	657.6774	90.9100
7/16	548.9486	83.0560			
1/2	551.5471	83.2524	29 in.	660.5214	91.1064
9/16	554.1519	83.4487	1/16	663.3716	91.3027
5/8	556.7627	83.6451	1/8	666.2278	91.4991
1 1/16	559.3797	83.8414	3/16	669.0902	91.6954
3/4	562.0027	84.0378	1/4	671.9587	91.8918
1 3/16	564.6320	84.2341	5/16	674.8335	92.0081
7/8	567.2674	84.4305	3/8	677.7143	92.2845
1 5/16	569.4090	84.6268	7/16	680.6013	92.4808

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
$\frac{1}{2}$	683.4943	92.6772	32 in.	804.2496	100.5312
$\frac{9}{16}$	686.3936	92.8735	$\frac{1}{16}$	807.3943	100.7275
$\frac{5}{8}$	689.2989	93.0699	$\frac{1}{8}$	810.5450	100.9240
$\frac{11}{16}$	692.2104	93.2662	$\frac{3}{16}$	813.7020	101.1202
$\frac{3}{4}$	695.1280	93.4626	$\frac{1}{4}$	816.8650	101.3166
$\frac{13}{16}$	698.0518	93.6589	$\frac{5}{16}$	820.0343	101.5130
$\frac{7}{8}$	700.9817	93.8553	$\frac{3}{8}$	823.2096	101.7093
$\frac{15}{16}$	703.9178	94.0516	$\frac{7}{16}$	826.3911	101.9056
			$\frac{1}{2}$	829.5787	102.1020
30 in	706.8600	94.2480	$\frac{9}{16}$	832.7725	102.2983
$\frac{1}{16}$	709.8083	94.4443	$\frac{5}{8}$	835.9724	102.4947
$\frac{1}{8}$	712.7627	94.6407	$\frac{11}{16}$	839.1784	102.6910
$\frac{3}{16}$	715.7233	94.8370	$\frac{3}{4}$	842.3905	102.8874
$\frac{1}{4}$	718.6900	95.0334	$\frac{13}{16}$	845.6089	103.0837
$\frac{5}{16}$	721.6629	95.2297	$\frac{7}{8}$	848.8333	103.2801
$\frac{3}{8}$	724.6419	95.4261	$\frac{15}{16}$	852.0639	103.4764
$\frac{7}{16}$	727.6271	95.6224			
$\frac{1}{2}$	730.6183	95.8188	33 in.	855.3006	103.6728
$\frac{9}{16}$	733.6158	96.0151	$\frac{1}{16}$	858.5436	103.8691
$\frac{5}{8}$	736.6193	96.2115	$\frac{1}{8}$	861.7924	104.0655
$\frac{11}{16}$	739.6290	96.4078	$\frac{3}{16}$	865.0475	104.2618
$\frac{3}{4}$	742.6447	96.6042	$\frac{1}{4}$	868.3087	104.4582
$\frac{13}{16}$	745.6667	96.8005	$\frac{5}{16}$	871.5760	104.6545
$\frac{7}{8}$	748.6948	96.9969	$\frac{3}{8}$	874.8497	104.8509
$\frac{15}{16}$	751.7291	97.1932	$\frac{7}{16}$	878.1290	105.0472
			$\frac{1}{2}$	881.4151	105.2436
31 in.	754.7694	97.3896	$\frac{9}{16}$	884.7070	105.4399
$\frac{1}{16}$	757.8159	97.5859	$\frac{5}{8}$	888.0051	105.6363
$\frac{1}{8}$	760.8685	97.7823	$\frac{11}{16}$	891.3090	105.8326
$\frac{3}{16}$	763.9273	97.9786	$\frac{3}{4}$	894.6196	106.0290
$\frac{1}{4}$	766.9921	98.1750	$\frac{13}{16}$	897.9369	106.2253
$\frac{5}{16}$	770.0632	98.3713	$\frac{7}{8}$	901.2587	106.4217
$\frac{3}{8}$	773.1404	98.5677	$\frac{15}{16}$	904.5875	106.6180
$\frac{7}{16}$	776.2237	98.7648			
$\frac{1}{2}$	779.3131	98.9684	34 in.	907.9224	106.8144
$\frac{9}{16}$	782.4087	99.1567	$\frac{1}{16}$	911.2645	107.0107
$\frac{5}{8}$	785.5104	99.3531	$\frac{1}{8}$	914.6105	107.2071
$\frac{11}{16}$	788.6183	99.5494	$\frac{3}{16}$	917.9640	107.4034
$\frac{3}{4}$	791.7322	99.7458	$\frac{1}{4}$	921.3232	107.5998
$\frac{13}{16}$	794.8524	99.9421	$\frac{5}{16}$	924.6883	107.7961
$\frac{7}{8}$	797.9786	100.1385	$\frac{3}{8}$	928.0605	107.9925
$\frac{15}{16}$	801.1111	100.3348	$\frac{7}{16}$	931.4380	108.1888

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	934.8223	108.3852	37 in.	1075.2126	116.2392
9/16	938.2121	108.5815	1/16	1078.8482	116.4355
5/8	941.6087	108.7779	1/8	1082.4898	116.6319
11/16	945.0110	108.9742	3/16	1086.1376	116.8282
3/4	948.4195	109.1706	1/4	1089.7915	117.0246
13/16	951.8341	109.3669	5/16	1093.4517	117.2209
7/8	955.2550	109.5633	3/8	1097.1179	117.4173
15/16	958.6820	109.7596	7/16	1100.7903	117.6136
			1/2	1104.4687	117.8100
35 in.	962.1150	109.9560	9/16	1108.1534	118.0063
1/16	965.5542	110.1523	5/8	1111.8441	118.2027
1/8	968.9995	110.3487	11/16	1115.5410	118.3990
3/16	972.4510	110.5450	3/4	1119.2440	118.5954
1/4	975.9085	110.7414	13/16	1122.9532	118.7917
5/16	979.3686	110.9377	7/8	1126.6685	118.9881
3/8	982.8422	111.1341	15/16	1130.3900	119.1844
7/16	986.3180	111.3304			
1/2	989.8003	111.5268	38 in.	1134.1176	119.3808
9/16	993.2097	111.7231	1/16	1137.8513	119.5771
5/8	996.7830	111.9195	1/8	1141.5911	119.7735
11/16	1000.3472	112.1158	3/16	1145.3371	119.9698
3/4	1003.7902	112.3122	1/4	1149.0892	120.1662
13/16	1007.3030	112.5086	5/16	1152.8475	120.3625
7/8	1010.8220	112.7049	3/8	1156.6119	120.5589
15/16	1014.3472	112.9012	7/16	1160.3825	120.7552
			1/2	1164.1591	120.9516
36 in.	1017.8784	113.0976	9/16	1167.9420	121.1479
1/16	1021.4158	113.2939	5/8	1171.7309	121.3443
1/8	1024.9592	113.4903	11/16	1175.5260	121.5406
3/16	1028.5089	113.6866	3/4	1179.3271	121.7370
1/4	1032.0646	113.8830	13/16	1183.1345	121.9333
5/16	1035.6266	114.0793	7/8	1186.9480	122.1297
3/8	1039.1946	114.2757	15/16	1190.7677	122.3260
7/16	1042.7913	114.4720			
1/2	1046.3941	114.6684	39 in.	1194.5934	122.5224
9/16	1049.9581	114.8647	1/16	1198.4253	122.7187
5/8	1053.5281	115.0611	1/8	1202.2633	122.9151
11/16	1057.1269	115.2572	3/16	1206.1075	123.1114
3/4	1060.7317	115.4538	1/4	1209.9577	123.3078
13/16	1064.3428	115.6501	5/16	1213.8142	123.5041
7/8	1067.9599	115.8465	3/8	1217.6768	123.7005
15/16	1071.5832	116.0428	7/16	1221.5455	123.8968

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1225.4203	124.0932	42 in.	1385.4456	131.9472
9/16	1229.3013	124.2895	1/16	1389.5720	132.1435
5/8	1233.1884	124.4859	1/8	1393.7045	132.3399
11/16	1237.0817	124.6822	3/16	1397.8432	132.5362
3/4	1240.9810	124.8786	1/4	1401.9880	132.7326
13/16	1244.8866	125.0749	5/16	1406.1390	132.9289
7/8	1248.7982	125.2713	3/8	1410.2961	133.1253
15/16	1252.7161	125.4676	7/16	1414.4594	133.3216
			1/2	1418.6287	133.5180
40 in.	1256.6400	125.6640	9/16	1422.8043	133.7143
1/16	1260.5701	125.8603	5/8	1426.9859	133.9107
1/8	1264.5062	126.0567	11/16	1431.1737	134.1070
3/16	1268.4486	126.2530	3/4	1435.3675	134.3034
1/4	1272.3970	126.4494	13/16	1439.5676	134.4997
5/16	1276.3517	126.6457	7/8	1443.7738	134.6961
3/8	1280.3124	126.8421	15/16	1447.9862	134.8924
7/16	1284.2793	127.0384			
1/2	1288.2523	127.2348	43 in.	1452.2046	135.0888
9/16	1292.2315	127.4311	1/16	1456.4292	135.2851
5/8	1296.2168	127.6275	1/8	1460.6599	135.4815
11/16	1300.2082	127.8238	3/16	1464.8968	135.6778
3/4	1304.2057	128.0202	1/4	1469.1397	135.8742
13/16	1308.2095	128.2165	5/16	1473.3839	136.0705
7/8	1312.2193	128.4129	3/8	1477.6342	136.2669
15/16	1316.2353	128.6092	7/16	1481.9006	136.4632
			1/2	1486.1731	136.6596
41 in.	1320.2574	128.8056	9/16	1490.4468	136.8559
1/16	1324.2857	129.0019	5/8	1494.7266	137.0523
1/8	1328.3200	129.1983	11/16	1499.0126	137.2486
3/16	1332.3605	129.3946	3/4	1503.3046	137.4450
1/4	1336.4071	129.5910	13/16	1507.6029	137.6413
5/16	1340.4600	129.7873	7/8	1511.9072	137.8377
3/8	1344.5189	129.9837	15/16	1516.2178	138.0340
7/16	1348.5840	130.1800			
1/2	1352.6551	130.3764	44 in.	1520.5344	138.2304
9/16	1356.7325	130.5727	1/16	1524.8572	138.4267
5/8	1360.8159	130.7691	1/8	1529.1860	138.6231
11/16	1364.9055	130.9654	3/16	1533.5211	138.8194
3/4	1369.0012	131.1618	1/4	1537.8622	139.0158
13/16	1373.1031	131.3581	5/16	1542.2046	139.2121
7/8	1377.2111	131.5545	3/8	1546.5530	139.4085
15/16	1381.3253	131.7508	7/16	1550.9176	139.6048

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1555.2883	139.8012	47 in.	1734.9486	147.6552
9/16	1559.6602	139.9975	1/16	1739.5659	147.8515
5/8	1564.0382	140.1939	1/8	1744.1893	148.0479
1 1/16	1568.4223	140.3902	3/16	1748.8189	148.2442
3/4	1572.8125	140.5866	1/4	1753.4545	148.4406
1 3/16	1577.2090	140.7829	5/16	1758.0914	148.6369
7/8	1581.6115	140.9793	3/8	1762.7344	148.8333
1 5/16	1586.0203	141.1756	7/16	1767.3935	149.0296
			1/2	1772.0587	149.2260
45 in.	1590.4350	141.3720	9/16	1776.7251	149.4223
1/16	1594.4560	141.5683	5/8	1781.3976	149.6187
1/8	1599.2830	141.7647	1 1/16	1786.0763	149.8150
3/16	1603.7162	141.9610	3/4	1790.7610	150.0114
1/4	1608.1555	142.1574	1 3/16	1795.4520	150.2077
5/16	1612.5961	142.3537	7/8	1800.1490	150.4041
3/8	1617.0427	142.5501	1 5/16	1804.8523	150.6004
7/16	1621.5055	142.7464			
1/2	1625.9743	142.9428	48 in.	1809.5616	150.7968
9/16	1630.4444	143.1391	1/16	1814.2551	150.9931
5/8	1634.9205	143.3355	1/8	1818.9986	151.1895
1 1/16	1639.4028	143.5318	3/16	1823.7264	151.3858
3/4	1643.8912	143.7282	1/4	1828.4602	151.5822
1 3/16	1648.3858	143.9245	5/16	1833.1953	151.7785
7/8	1652.8865	144.1209	3/8	1837.9364	151.9749
1 5/16	1657.3934	144.3172	7/16	1842.6937	152.1712
			1/2	1847.4571	152.3676
46 in.	1661.9064	144.5136	9/16	1852.2167	152.5639
1/16	1666.4255	144.7099	5/8	1856.9924	152.7603
1/8	1670.9507	144.9063	1 1/16	1861.7892	152.9566
3/16	1675.4821	145.1026	3/4	1868.5521	153.1530
1/4	1680.0196	145.2990	1 3/16	1871.3413	153.3493
5/16	1684.5583	145.4953	7/8	1876.1365	153.5457
3/8	1689.1031	145.6917	1 5/16	1880.9379	153.7420
7/16	1693.6641	145.8880			
1/2	1698.2311	146.0844	49 in.	1885.7454	153.9384
9/16	1702.7994	146.2807	1/16	1890.5591	154.1347
5/8	1707.3737	146.4771	1/8	1895.3788	154.3311
1 1/16	1711.9542	146.6734	3/16	1900.2047	154.5274
3/4	1716.5407	146.8698	1/4	1905.0367	154.7238
1 3/16	1721.1335	147.0661	5/16	1909.8700	154.9201
7/8	1725.7324	147.2625	3/8	1914.7093	155.1165
1 5/16	1730.3375	147.4588	7/16	1919.5648	155.3128

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	1924.4263	155.5092	52 in.	2123.7216	163.3632
9/16	1929.2891	155.7055	1/16	2128.8298	163.5595
5/8	1934.1579	155.9019	1/8	2133.9440	163.7559
11/16	1939.0329	156.0982	3/16	2139.0645	163.9522
3/4	1943.9140	156.2946	1/4	2144.1910	164.1486
13/16	1948.8013	156.4909	5/16	2149.3238	164.3449
7/8	1953.6947	156.6873	3/8	2154.4626	164.5413
15/16	1958.0943	156.8836	7/16	2159.6076	164.7376
			1/2	2164.7587	164.9340
50 in.	1963.5000	157.0800	9/16	2169.9160	165.1303
1/16	1968.4118	157.2763	5/8	2175.0794	165.3267
1/8	1973.3297	157.4727	11/16	2180.2489	165.5230
3/16	1978.2525	157.6690	3/4	2185.4245	165.7194
1/4	1983.1840	157.8654	13/16	2190.6064	165.9157
5/16	1988.6154	158.0617	7/8	2195.7943	166.1121
3/8	1993.0529	158.2581	15/16	2200.9884	166.3084
7/16	1998.0066	158.4544			
1/2	2002.9663	158.6508	53 in.	2206.1886	166.5048
9/16	2007.9273	158.8471	1/16	2211.3950	166.7011
5/8	2012.8943	159.0435	1/8	2216.6074	166.8975
11/16	2017.8675	159.2398	3/16	2221.8260	167.0938
3/4	2022.8467	159.4362	1/4	2227.0507	167.2902
13/16	2027.8172	159.6325	5/16	2232.2817	167.4865
7/8	2032.8238	159.8289	3/8	2237.5187	167.6829
15/16	2037.8216	160.0252	7/16	2242.7619	167.8792
			1/2	2248.0111	168.0756
51 in.	2042.8254	160.2216	9/16	2253.2666	168.2719
1/16	2047.8354	160.4179	5/8	2258.5281	168.4683
1/8	2052.8515	160.6143	11/16	2263.7908	168.6646
3/16	2057.8798	160.8106	3/4	2269.0696	168.8610
1/4	2062.9021	161.0070	13/16	2274.3496	169.0573
5/16	2067.9317	161.2033	7/8	2279.6357	169.2537
3/8	2072.9674	161.3997	15/16	2284.9280	169.4500
7/16	2078.0293	161.5960			
1/2	2083.0771	161.7924	54 in.	2290.2264	169.6464
9/16	2088.1362	161.9887	1/16	2295.5309	169.8427
5/8	2093.2014	162.1851	1/8	2300.8415	170.0391
11/16	2098.2678	162.3814	3/16	2306.1583	170.2354
3/4	2103.3502	162.5778	1/4	2311.4812	170.4318
13/16	2108.4339	162.7741	5/16	2316.8163	170.6281
7/8	2113.5236	162.9705	3/8	2322.1455	170.8245
15/16	2118.1196	163.1668	7/16	2327.4819	171.0208

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
55 in.	2375.8350	172.7880	57 in.	2551.7646	179.0712
	2381.2382	172.9843		2557.3637	179.2675
	2386.6465	173.1807		2562.9688	179.4639
	2392.0515	173.3770		2568.5801	179.6602
	2397.4825	173.5734		2574.1975	179.8566
	2402.9098	173.7697		2579.8212	180.0529
	2408.3432	173.9661		2585.4509	180.2493
	2413.7777	174.1624		2591.0869	180.4456
	2419.2283	174.3588		2596.7287	180.6420
	2424.7026	174.5551		2602.3769	180.8383
	2430.1830	174.7515		2608.0311	181.0347
	2435.6246	174.9478		2613.6942	181.2310
	2441.0722	175.1442		2619.3580	181.4274
	2446.5486	175.3405		2625.0307	181.6237
	2452.0310	175.5369		2630.7095	181.8201
	2457.0197	175.7332		2636.3945	182.0164
56 in.	2463.0144	175.9296	58 in.	2642.0856	182.2128
	2468.5153	176.1259		2647.7328	182.4091
	2474.0222	176.3223		2653.4861	182.6055
	2479.5354	176.5186		2659.9565	182.8018
	2485.0546	176.7150		2664.9112	182.9982
	2490.5351	176.9913		2670.6330	183.1945
	2496.1116	177.1077		2676.3609	183.3909
	2501.6493	177.3040		2682.0950	183.5872
	2507.1931	177.5004		2687.8351	183.7836
	2512.7431	177.6967		2693.5814	183.9799
	2518.2992	177.8931		2699.3338	184.1763
	2523.8614	178.0894		2705.0924	184.3726
	2529.4297	178.2858		2710.8571	184.5690
	2535.0043	178.4821		2716.6280	184.7653
	2540.5849	178.6785		2722.4050	184.9617
	2546.1717	178.8748		2728.1882	185.1580
			59 in.	2733.9774	185.3544
				2739.7728	185.5507
				2745.5743	185.7471
				2751.8820	185.9434
				2757.1957	186.1398
				2763.0157	186.3361
				2768.8418	186.5325
				2774.6745	186.7288

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
$\frac{1}{2}$	2780.5123	186.9252	62 in.	3019.0776	194.7792
$\frac{9}{16}$	2786.3568	187.1215	$\frac{1}{16}$	3025.1675	194.9755
$\frac{5}{8}$	2792.2074	187.3179	$\frac{1}{8}$	3031.2635	195.1719
$\frac{11}{16}$	2798.0642	187.5142	$\frac{3}{16}$	3037.3607	195.3682
$\frac{3}{4}$	2803.9270	187.7106	$\frac{1}{4}$	3043.4740	195.5646
$\frac{13}{16}$	2809.7461	187.9069	$\frac{5}{16}$	3049.6885	195.7609
$\frac{7}{8}$	2815.6712	188.1033	$\frac{3}{8}$	3055.7091	195.9573
$\frac{15}{16}$	2821.5526	188.2996	$\frac{7}{16}$	3061.8359	196.1536
			$\frac{1}{2}$	3067.9687	196.3500
60 in.	2827.4400	188.4960	$\frac{9}{16}$	3074.1578	196.5463
$\frac{1}{16}$	2833.3336	188.6923	$\frac{5}{8}$	3080.2529	196.7427
$\frac{1}{8}$	2839.2332	188.8887	$\frac{11}{16}$	3086.4042	196.9390
$\frac{3}{16}$	2845.1391	189.0850	$\frac{3}{4}$	3092.5615	197.1354
$\frac{1}{4}$	2851.0510	189.2814	$\frac{13}{16}$	3098.7251	197.3317
$\frac{5}{16}$	2856.9692	189.4777	$\frac{7}{8}$	3104.8948	197.5281
$\frac{3}{8}$	2862.8934	189.6741	$\frac{15}{16}$	3111.0707	197.7244
$\frac{7}{16}$	2868.8223	189.8704			
$\frac{1}{2}$	2874.7603	189.0668	63 in.	3117.2526	197.9208
$\frac{9}{16}$	2880.7030	190.2631	$\frac{1}{16}$	3124.4407	198.1171
$\frac{5}{8}$	2886.6517	190.4595	$\frac{1}{8}$	3129.6349	198.3135
$\frac{11}{16}$	2892.6067	190.6558	$\frac{3}{16}$	3135.8353	198.5098
$\frac{3}{4}$	2898.5677	190.8522	$\frac{1}{4}$	3142.0417	198.7062
$\frac{13}{16}$	2904.5350	191.0485	$\frac{5}{16}$	3148.7544	198.9025
$\frac{7}{8}$	2910.5083	191.2449	$\frac{3}{8}$	3154.4732	199.0989
$\frac{15}{16}$	2916.4878	191.4412	$\frac{7}{16}$	3160.7981	199.2952
			$\frac{1}{2}$	3166.9291	199.4916
61 in.	2922.4734	191.6376	$\frac{9}{16}$	3173.1663	199.6879
$\frac{1}{16}$	2928.4652	191.8339	$\frac{5}{8}$	3179.4096	199.8843
$\frac{1}{8}$	2934.4630	192.0303	$\frac{11}{16}$	3185.6591	200.0806
$\frac{3}{16}$	2940.4670	192.2266	$\frac{3}{4}$	3191.9146	200.2770
$\frac{1}{4}$	2946.4771	192.4230	$\frac{13}{16}$	3193.1764	200.4733
$\frac{5}{16}$	2952.4938	192.6193	$\frac{7}{8}$	3204.4442	200.6697
$\frac{3}{8}$	2958.5159	192.8157	$\frac{15}{16}$	3210.7183	200.8660
$\frac{7}{16}$	2964.5445	193.0120			
$\frac{1}{2}$	2970.5791	193.2084	64 in.	3216.9984	201.0624
$\frac{9}{16}$	2976.6200	193.4047	$\frac{1}{16}$	3223.2847	201.2587
$\frac{5}{8}$	2982.6669	193.6011	$\frac{1}{8}$	3229.5770	201.4551
$\frac{11}{16}$	2988.7200	193.7974	$\frac{3}{16}$	3235.8746	201.6514
$\frac{3}{4}$	2994.7792	193.9938	$\frac{1}{4}$	3242.1782	201.8478
$\frac{13}{16}$	3000.8423	194.1901	$\frac{5}{16}$	3248.4936	202.0441
$\frac{7}{8}$	3006.9161	194.3865	$\frac{3}{8}$	3254.8080	202.2405
$\frac{15}{16}$	3017.9938	194.5828	$\frac{7}{16}$	3261.1311	202.4368

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	3267.4603	202.6332	67 in.	3525.6606	210.4872
9/16	3273.7957	202.8295	1/16	3532.2414	210.6835
5/8	3280.1372	203.0259	1/8	3538.8283	210.8799
11/16	3286.4875	203.2222	3/16	3545.4200	211.0762
3/4	3292.8385	203.4186	1/4	3552.0185	211.2726
13/16	3299.1985	203.6149	5/16	3558.6249	211.4689
7/8	3305.5645	203.8113	3/8	3565.2374	211.6653
15/16	3311.9367	204.0076	7/16	3571.8550	211.8616
			1/2	3578.4787	212.0580
65 in.	3318.3151	204.2040	9/16	3585.1086	212.2543
1/16	3324.7495	204.4003	5/8	3591.7446	212.4507
1/8	3331.0900	204.5917	11/16	3598.8868	212.6470
3/16	3337.9857	204.7930	3/4	3605.0350	212.8434
1/4	3343.8875	204.9894	13/16	3611.6895	213.0397
5/16	3350.2976	205.1857	7/8	3618.3500	213.2361
3/8	3356.7137	205.3821	15/16	3625.0168	213.4324
7/16	3363.1350	205.5784			
1/2	3369.5623	205.7748	68 in.	3631.6896	213.6288
9/16	3375.9959	205.9711	1/16	3638.3686	213.8251
5/8	3382.4355	206.1675	1/8	3645.0536	214.0215
11/16	3388.8813	206.3638	3/16	3651.7439	214.2178
3/4	3395.3332	206.5602	1/4	3658.4402	214.4142
13/16	3401.7913	206.7565	5/16	3665.1448	214.6105
7/8	3408.2555	206.9529	3/8	3671.8554	214.8069
15/16	3414.7259	207.1492	7/16	3678.5762	215.0032
			1/2	3685.2931	215.1996
66 in.	3421.2024	207.3456	9/16	3692.0212	215.3959
1/16	3427.6850	207.5419	5/8	3698.7554	215.5923
1/8	3434.1737	207.7383	11/16	3703.9957	215.7886
3/16	3440.6676	207.9346	3/4	3712.2421	215.9850
1/4	3447.1676	208.1310	13/16	3718.9948	216.1813
5/16	3453.6758	208.3273	7/8	3725.7535	216.3777
3/8	3468.1901	208.5237	15/16	3732.5184	216.5748
7/16	3470.7096	208.7200			
1/2	3473.2351	208.9164	69 in.	3739.2894	216.7704
9/16	3479.7669	209.1127	1/16	3745.8166	216.9667
5/8	3486.3047	209.3091	1/8	3752.8498	217.1631
11/16	3492.8487	209.5054	3/16	3759.6382	217.3594
3/4	3499.3987	209.7018	1/4	3766.4327	217.5558
13/16	3506.4550	209.8981	5/16	3773.2355	217.7521
7/8	3512.5174	210.0945	3/8	3780.0443	217.9485
15/16	3519.0860	210.2908	7/16	3786.8628	218.1448

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	3793.6783	218.3412	72 in.	4071.5136	226.1952
9/16	3800.5191	218.5375	1/16	4078.5853	226.3915
5/8	3807.3369	218.7339	1/8	4085.6631	226.5879
1 1/16	3814.2781	218.9302	3/16	4092.7460	226.7842
3/4	3821.0200	219.1266	1/4	4099.8350	226.9806
1 3/16	3827.8708	219.3229	5/16	4106.9323	227.1769
7/8	3834.7277	219.5193	3/8	4114.0356	227.3733
1 5/16	3841.5908	219.7156	7/16	4121.1442	227.5696
			1/2	4128.2587	227.7660
70 in.	3848.4600	219.9120	9/16	4135.3795	227.9623
1/16	3855.8353	220.1083	5/8	4142.5064	228.1587
1/8	3862.2167	220.3047	1 1/16	4149.6394	228.3550
3/16	3869.1033	220.5010	3/4	4156.7785	228.5514
1/4	3875.9960	220.6974	1 3/16	4163.9239	228.7477
5/16	3882.8969	220.8937	7/8	4171.0753	228.9441
3/8	3889.8039	221.0901	1 5/16	4178.2329	229.1404
7/16	3896.7211	221.2864			
1/2	3903.6343	221.4828	73 in.	4185.3966	229.3368
9/16	3910.5588	221.6791	1/16	4192.5665	229.5331
5/8	3917.4893	221.8755	1/8	4199.7424	229.7295
1 1/16	3924.4260	222.0718	3/16	4206.9230	229.9258
3/4	3931.3687	222.2682	1/4	4214.1107	230.1222
1 3/16	3938.3177	222.4645	5/16	4221.3027	230.3185
7/8	3945.2728	222.6609	3/8	4228.5077	230.5149
1 5/16	3952.2341	222.8572	7/16	4235.7109	230.7112
			1/2	4242.9271	230.9076
71 in.	3959.2014	223.0536	9/16	4250.1461	231.1039
1/16	3966.1749	223.2499	5/8	4257.3711	231.3003
1/8	3973.1545	223.4463	1 1/16	4264.6023	231.4966
3/16	3980.1393	223.6426	3/4	4271.8396	231.6930
1/4	3987.1301	223.8390	1 3/16	4279.0831	231.8893
5/16	3994.1292	224.0353	7/8	4286.3327	232.0857
3/8	4001.1344	224.2317	1 5/16	4293.5885	232.2820
7/16	4008.1447	224.4380			
1/2	4015.1611	224.6244	74 in.	4300.8504	232.4784
9/16	4022.1837	224.8207	1/16	4308.1185	232.6747
5/8	4029.2124	225.0171	1/8	4315.3926	232.8711
1 1/16	4036.2473	225.2134	3/16	4322.1719	233.0674
3/4	4043.2882	225.4098	1/4	4329.9572	233.2638
1 3/16	4050.3354	225.6061	5/16	4337.2508	233.4601
7/8	4057.3886	225.8025	3/8	4344.5505	233.6565
1 5/16	4064.4481	225.9988	7/16	4351.8551	233.8528

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	4359.1663	234.0492	77 in.	4656.6366	241.9032
9/16	4366.4835	234.2455	1/16	4664.1992	242.0995
5/8	4373.8067	234.4419	1/8	4671.7678	242.2959
11/16	4381.1361	234.6382	3/16	4679.3416	242.4922
3/4	4388.4715	234.8346	1/4	4686.9215	242.6886
13/16	4396.3132	235.0309	5/16	4694.5097	242.8849
7/8	4403.1610	235.2273	3/8	4702.1039	243.0813
15/16	4410.5150	235.4236	7/16	4709.7033	243.2776
			1/2	4717.3087	243.4740
75 in.	4417.8750	235.6200	9/16	4724.9204	243.6703
1/16	4425.2412	235.8163	5/8	4732.5381	243.8667
1/8	4432.6135	236.0127	11/16	4740.1620	244.0630
3/16	4439.9910	236.2090	3/4	4747.7920	244.2594
1/4	4447.3745	236.4054	13/16	4755.8782	244.4557
5/16	4454.7663	236.6017	7/8	4763.0705	244.6521
3/8	4462.1642	236.7981	15/16	4771.1690	244.8484
7/16	4469.5672	236.9944			
1/2	4476.9763	237.1908	78 in.	4778.3736	245.0448
9/16	4484.3916	237.3871	1/16	4786.0344	245.2411
5/8	4491.8130	237.5835	1/8	4793.7012	245.4375
11/16	4499.2406	237.7798	3/16	4801.3732	245.6338
3/4	4506.6742	237.9762	1/4	4809.0512	245.8302
13/16	4514.1141	238.1725	5/16	4817.1375	246.0265
7/8	4521.5600	238.3689	3/8	4824.4299	246.2229
15/16	4528.9622	238.5652	7/16	4832.1275	246.4192
			1/2	4839.8311	246.6156
76 in.	4536.4704	238.7616	9/16	4847.5409	246.8119
1/16	4543.9333	238.9579	5/8	4855.2568	247.0083
1/8	4551.4023	239.1543	11/16	4862.9789	247.2046
3/16	4558.8794	239.3506	3/4	4870.7071	247.4010
1/4	4566.3626	239.5470	13/16	4878.4415	247.5973
5/16	4573.8526	239.7433	7/8	4886.1820	247.7937
3/8	4581.3486	239.9397	15/16	4893.9287	247.9900
7/16	4588.8493	240.1360			
1/2	4596.3571	240.3324	79 in.	4901.6814	248.1864
9/16	4603.8706	240.5287	1/16	4909.4403	248.3827
5/8	4611.3902	240.7251	1/8	4917.2053	248.5791
11/16	4618.9159	240.9214	3/16	4924.9755	248.7754
3/4	4626.4477	241.1178	1/4	4932.7517	248.9718
13/16	4633.9858	241.3141	5/16	4940.5362	249.1681
7/8	4641.5299	241.5105	3/8	4948.3268	249.3645
15/16	4649.0802	241.7068	7/16	4956.1225	249.5608

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	4963.9243	249.7572	82 in.	5281.0296	257.6112
9/16	4971.7319	249.9535	1/16	5289.0781	257.8075
5/8	4979.5456	250.1499	1/8	5297.1426	258.0039
11/16	4987.3663	250.3462	3/16	5305.2073	258.2002
3/4	4995.1930	250.5426	1/4	5313.2780	258.3966
13/16	5003.0316	250.7389	5/16	5321.3570	258.5929
7/8	5010.8642	250.9353	3/8	5329.4421	258.7893
15/16	5018.7091	251.1316	7/16	5337.5324	258.9856
			1/2	5345.6287	259.1820
30 in.	5026.5600	251.3280	9/16	5353.7809	259.3783
1/16	5034.4171	251.5243	5/8	5361.8391	259.5747
1/8	5042.2803	251.7207	11/16	5369.9543	259.7710
3/16	5050.1486	251.9170	3/4	5378.0755	259.9674
1/4	5058.0230	252.1134	13/16	5386.2026	260.1637
5/16	5065.9027	252.3097	7/8	5394.3358	260.3601
3/8	5073.7944	252.5061	15/16	5402.4552	260.5564
7/16	5081.6883	252.7024			
1/2	5089.5883	252.8988	83 in.	5410.6206	260.7528
9/16	5097.4941	253.0951	1/16	5418.7722	260.9491
5/8	5105.4060	253.2915	1/8	5426.9299	261.1455
11/16	5113.8248	253.4878	3/16	5435.0928	261.3418
3/4	5121.2497	253.6842	1/4	5443.2617	261.5382
13/16	5129.1855	253.8805	5/16	5451.4389	261.7345
7/8	5137.1173	254.0769	3/8	5459.6222	261.9309
15/16	5145.0603	254.2732	7/16	5467.8106	262.1272
			1/2	5476.0051	262.3236
81 in.	5153.0094	254.4696	9/16	5484.2054	262.5199
1/16	5160.9647	254.6659	5/8	5492.4118	262.7163
1/8	5168.9260	254.8623	11/16	5500.6252	262.9126
3/16	5176.8925	255.0586	3/4	5508.8446	263.1090
1/4	5184.8651	255.2550	13/16	5517.0699	263.3053
5/16	5192.8460	255.4513	7/8	5525.3012	263.5017
3/8	5200.8329	255.6477	15/16	5533.5388	263.6980
7/16	5208.8250	255.8440			
1/2	5216.8231	256.0404	84 in.	5541.7824	263.8944
9/16	5224.8271	256.2367	1/16	5550.0322	264.0907
5/8	5232.8371	256.4331	1/8	5558.2881	264.2871
11/16	5240.8568	256.6294	3/16	5566.5491	264.4834
3/4	5248.8772	256.8258	1/4	5574.8162	264.6798
13/16	5256.9061	257.0221	5/16	5583.0916	264.8761
7/8	5264.9411	257.2105	3/8	5591.3730	265.0725
15/16	5272.9828	257.4148	7/16	5599.6596	265.2688

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	5607.9523	265.4652	87 in.	5944.6926	273.3192
9/16	5616.2508	265.6615	1/16	5953.2369	273.5155
5/8	5624.5554	265.8579	1/8	5961.7873	273.7119
1 1/16	5632.8662	266.0542	3/16	5970.3429	273.9082
3/4	5641.1845	266.2506	1/4	5978.9045	274.1046
1 3/16	5649.5071	266.4469	5/16	5987.4749	274.3009
7/8	5657.8357	266.6433	3/8	5996.0504	274.4973
1 5/16	5666.1723	266.8396	7/16	6004.6315	274.6936
			1/2	6013.2187	274.8900
85 in.	5674.5150	267.0360	9/16	6021.8117	275.0863
1/16	5682.8630	267.2323	5/8	6030.4108	275.2827
1/8	5691.2170	267.4287	1 1/16	6039.0169	275.4790
3/16	5699.5762	267.6250	3/4	6047.6290	275.6754
1/4	5707.9415	267.8214	1 3/16	6056.2470	275.8717
5/16	5716.3151	268.0177	7/8	6064.8710	276.0681
3/8	5724.6947	268.2141	1 5/16	6073.5013	276.2644
7/16	5733.0795	268.4104			
1/2	5741.4703	268.6068	88 in.	6082.1376	276.4608
9/16	5749.8670	268.8031	1/16	6090.7801	276.6671
5/8	5758.2697	268.9997	1/8	6099.4287	276.8535
1 1/16	5766.6794	269.1958	3/16	6108.0824	277.0498
3/4	5775.0952	269.3922	1/4	6116.7422	277.2462
1 3/16	5783.5168	269.5885	5/16	6125.4103	277.4425
7/8	5791.9445	269.7849	3/8	6134.0844	277.6389
1 5/16	5800.3784	269.9812	7/16	6144.2637	277.8352
			1/2	6151.4491	278.0316
86 in.	5808 8184	270.1776	9/16	6160.1403	278.2279
1/16	5817.2651	270.3739	5/8	6169.8376	278.4243
1/8	5825.7168	270.5703	1 1/16	6177.5418	278.6206
3/16	5834.1742	270.7666	3/4	6186.2521	278.8170
1/4	5842.6376	270.9630	1 3/16	6194.9683	279.0133
5/16	5851.1093	271.1593	7/8	6203.6905	279.2097
3/8	5859.5871	271.3557	1 5/16	6212.4189	279.4060
7/16	5868.0701	271.5520			
1/2	5876.5591	271.7484	89 in.	6221.1534	279.6024
9/16	5885.0540	271.9447	1/16	6229.8941	279.7987
5/8	5893.5549	272.1411	1/8	6238.6408	279.9951
1 1/16	5902.0620	272.3374	3/16	6247.3927	280.1914
3/4	5910.5767	272.5338	1/4	6256.1507	280.3878
1 3/16	5919.0965	272.7301	5/16	6264.9170	280.5841
7/8	5927.6224	272.9265	3/8	6273.6893	280.7805
1 5/16	5936.1545	273.1228	7/16	6282.4668	280.9768

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/16	6291.2503	281.1732	92 in.	6647.6258	289.0272
2/16	6300.0397	281.3695	1/16	6656.6609	289.2235
3/16	6308.8351	281.5659	1/8	6665.7021	289 4199
4/16	6317.6375	281.7622	3/16	6674.7485	289.6162
3/4	6326.4460	281.9586	1/4	6683.8010	289.8125
6/16	6335.2603	282.1549	5/16	6692.8618	290.0089
7/8	6344.0807	282.3513	3/8	6701.9286	290.2053
8/16	6352.9073	282.5476	7/16	6711.5001	290.4016
			1/2	6720.0787	290.5980
90 in.	6361.7400	282.7440	9/16	6729.6628	290.7943
1/16	6370.5789	282.9403	5/8	6738.2530	290.9907
1/8	6379.4238	283.1367	1 1/16	6747.3497	291.1870
3/16	6388.7739	283.3330	3/4	6756.4525	291.3834
1/4	6397.1300	283.5294	13/16	6765.5614	291.5797
5/16	6405.9944	283.7257	7/8	6774.6763	291.7761
3/8	6414.8649	283.9221	15/16	6783.7975	291.9724
7/16	6423.7906	284.1184			
1/2	6432.6223	284.3148	93 in.	6792.9248	292.1688
9/16	6441.5101	284.5111	1/16	6802.0581	292.3651
5/8	6450.4039	284.7075	1/8	6811.1974	292.5615
1 1/16	6459.3043	284.9038	3/16	6820.3420	292.7578
3/4	6468.2107	285.1002	1/4	6829.4927	292.9542
13/16	6477.1232	285.2965	5/16	6838.6517	293.1505
7/8	6486.0418	285.4929	3/8	6847.8167	293.3469
15/16	6494.9566	285.6892	7/16	6856.9869	293.5432
			1/2	6866.1631	293.7396
91 in.	6503.8974	285.8856	9/16	6875.3454	293.9359
1/16	6512.8344	286.0819	5/8	6884.5338	294.1323
1/8	6521.7775	286.2783	1 1/16	6893.7337	294.3286
3/16	6530.7258	286.4746	3/4	6902.9296	294.5250
1/4	6539.6801	286.6710	13/16	6912.1366	294.7213
5/16	6548.6427	286.8673	7/8	6921.3497	294.9177
3/8	6557.6114	287.0637	15/16	6930.5691	295.1140
7/16	6566.5857	287.2600			
1/2	6573.5651	287.4564	94 in.	6939.7946	295.3104
9/16	6584.5511	287.6527	1/16	6949.5261	295.5067
5/8	6593.5431	287.8491	1/8	6958.2636	295.7031
1 1/16	6602.5443	288.0454	3/16	6968.0064	295.8994
3/4	6611.5462	288.2418	1/4	6976.7552	296.0958
13/16	6620.5569	288.4381	5/16	6986.0123	296.2921
7/8	6629.5736	288.6345	3/8	6995.2755	296.4885
15/16	6638.5967	288.8388	7/16	7004.5439	296.6848

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
1/2	7013.8183	296.8812	97 in.	7389.8288	304.7352
9/16	7023.0988	297.0775	1/16	7399.3548	304.9315
5/8	7032.3853	297.2739	1/8	7408.8868	305.1279
11/16	7041.6784	297.4702	3/16	7418.6241	305.3242
3/4	7050.9775	297.6666	1/4	7427.9675	305 5206
13/16	7060.2827	297.8629	5/16	7437.5192	305.7169
7/8	7069.5940	298.0593	3/8	7447.0769	305.9133
15/16	7075.9116	298.2556	7/16	7456.6398	306.1096
			1/2	7466.2087	306.3060
95 in.	7088.2352	298.4520	9/16	7475.7837	306.5023
1/16	7097.5738	298.6483	5/8	7485.3648	306.6987
1/8	7106.9005	298.8447	11/16	7494.9524	306.8950
3/16	7116.7415	299.0400	3/4	7504.5460	307 0914
1/4	7125.5885	299.2374	13/16	7514.1457	307.2877
5/16	7134.9443	299.4337	7/8	7523.7515	307.4841
3/8	7144.3052	299.6301	15/16	7533.3636	307.6804
7/16	7153.6717	299.8264			
1/2	7163.0443	300.0228	98 in.	7542.9818	307.8768
9/16	7172.4230	300.2191	1/16	7552.6060	308.0731
5/8	7181.8077	300.4155	1/8	7562.2362	308.2695
11/16	7191.1989	300.6118	3/16	7575.8717	308.4658
3/4	7200.5962	300.8082	1/4	7581.5132	308.6622
13/16	7209.9096	301.0045	5/16	7591.1630	308.8585
7/8	7219.4090	301.2009	3/8	7600.8189	309.0549
15/16	7228.8248	301.3972	7/16	7610.4800	309.2512
			1/2	7620.1471	309.4476
96 in.	7238.2466	301.5936	9/16	7629.8203	309.6439
1/16	7247.6741	301.7899	5/8	7639.4995	309.8403
1/8	7257.1083	301.9863	11/16	7649.1853	310.0366
3/16	7266.5474	302.1826	3/4	7658.8771	310.2330
1/4	7275.9926	302.3790	13/16	7668.5750	310.4293
5/16	7285.4461	302.5753	7/8	7678.2790	310.6257
3/8	7294.9056	302.7717	15/16	7687.9893	310.8220
7/16	7304.3703	302.9680			
1/2	7313.8411	303.1644	99 in.	7697.7056	311.0184
9/16	7323.3179	303.3607	1/16	7707.4279	311.2147
5/8	7332.8008	303.5571	1/8	7717.1563	311.4111
11/16	7342.2902	303.7534	3/16	7726.8900	311.6074
3/4	7351.7857	303.9498	1/4	7736.6297	311.8038
13/16	7361.2873	304.1461	5/16	7746.3777	312.0001
7/8	7370.7949	304.3425	3/8	7756.1318	312.1965
15/16	7380.3088	304.5388	7/16	7765.8910	312.3928

DIAMETERS, AREAS, ETC.—*Continued.*

Dia.	Area.	Circum.	Dia.	Area.	Circum.
½	7775.6563	312.5892	½	8413.4008	325.1556
9/16	7785.4277	312.7855	¾	8454.0944	325.9410
⅝	7795.2051	312.9819			
11/16	7804.9890	313.0782	104 in.	8494.8864	326.7264
¾	7814.7790	313.3746	¼	8535.7760	327.5118
13/16	7824.5751	313.5709	½	8576.7640	328.2972
⅞	7834.3772	313.7673	¾	8617.8504	329.0826
15/16	7844.1856	313.9636			
			105 in.	8659.0348	329.8680
100 in.	7854.0000	314.1600	¼	8700.3176	330.6534
¼	7893.3190	314.9454	½	8741.6980	331.4388
½	7932.7360	315.7308	¾	8783.1772	332.2242
¾	7972.2120	316.5162			
			106 in.	8824.7544	333.0096
101 in.	8011.8652	317.3016	½	8908.2028	334.5804
¼	8051.5772	318.0870			
½	8091.3870	318.8724	107 in.	8992.0444	336.1512
¾	8131.2953	319.6578	½	9076.2784	337.7220
102 in.	8171.3016	320.4432	108 in.	9160.9056	339.2928
¼	8211.4060	321.2286	½	9245.9248	340.8636
½	8251.6084	322.0140			
¾	8291.8696	322.7994	109 in.	9331.3372	342.4344
			½	9417.1420	344.0052
103 in.	8332.3085	323.5848			
¼	8372.8056	324.3702	110 in.	9503.3400	345.5760

A Table of Diameters, Areas, and Circumferences of Circles, in Feet, from 1 to 50 Feet.

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
1 ft.	.7854	3 1 5/8	2	13.6353	13 1
1	.9217	3 4 5/8	3	14.1862	13 4 1/2
2	1.0690	3 8	4	14.7479	13 7 1/4
3	1.2271	3 11	5	15.3206	13 10 1/2
4	1.3962	4 2 1/8	6	15.9043	14 1 5/8
5	.5761	4 5 3/8	7	16.4986	14 4 5/8
6	1.7671	4 8 1/2	8	17.1041	14 7 7/8
7	1.9689	4 11 5/8	9	17.7205	14 11
8	2.1816	5 2 3/4	10	18.3476	15 2 1/8
9	2.4052	5 5 7/8	11	18.9858	15 5 1/4
10	2.6398	5 9	5 ft.	19.6350	15 8 1/2
11	2.8852	6 2 1/4	1	20.2947	15 11 5/8
2 ft.	3.1416	6 3 5/8	2	20.9656	16 2 3/4
1	3.4087	6 6 1/2	3	21.6475	16 5 1/4
2	3.6869	6 9 5/8	4	22.3400	16 9
3	3.9760	7 0 3/4	5	23.0437	17 0 1/2
4	4.2760	7 3 7/8	6	23.7583	17 3 1/4
5	4.5869	7 7	7	24.4835	17 6 3/8
6	4.9087	7 10 1/4	8	25.2199	17 9 5/8
7	5.2413	8 1 3/8	9	25.9672	18 0 3/4
8	5.5850	8 4 1/2	10	26.7251	18 3 7/8
9	5.9395	8 7 5/8	11	27.4943	18 7 1/8
10	6.3049	8 10 3/4	6 ft.	28.2744	18 10 1/8
11	6.6813	9 1 7/8	1	29.0649	19 1 1/4
3 ft.	7.0686	9 5	2	29.8668	19 4 3/8
1	7.4666	9 8 1/4	3	30.6796	19 7 1/2
2	7.8757	9 11 3/8	4	31.5029	19 10 5/8
3	8.2957	10 2 1/2	5	32.3376	20 1 7/8
4	8.7265	10 5 5/8	6	33.1831	20 4 7/8
5	9.1683	10 8 3/4	7	34.0391	20 8 1/8
6	9.6211	10 11 7/8	8	34.9065	20 11 1/2
7	10.0846	11 3	9	35.7847	21 2 3/8
8	10.5591	11 6 1/8	10	36.6735	21 5 1/2
9	11.0446	11 9 3/8	11	37.5736	21 8 3/4
10	11.5409	12 0 1/2	7 ft.	38.4846	21 11 7/8
11	12.0481	12 3 5/8	1	39.4060	22 3
4 ft.	12.5664	12 6 3/4	2	40.3388	22 6 1/8
1	13.0952	12 9 7/8	3	41.2825	22 9 1/4

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.
4	42.2367	23 $0\frac{3}{8}$	6	86.5903	32 $11\frac{3}{4}$
5	43.2022	23 $2\frac{1}{8}$	7	87.9697	33 $2\frac{7}{8}$
6	44.1787	23 $6\frac{3}{4}$	8	89.3608	33 $6\frac{1}{8}$
7	45.1656	23 11	9	90.7627	33 $9\frac{1}{4}$
8	46.1638	24 $1\frac{1}{8}$	10	92.1749	34 $0\frac{3}{8}$
9	47.1730	24 $4\frac{1}{8}$	11	93.5986	34 $3\frac{1}{2}$
10	48.1926	24 $7\frac{1}{4}$	11 ft.	95.0334	34 $6\frac{5}{8}$
11	49.2236	24 $10\frac{3}{8}$	1	96.4783	34 $9\frac{3}{4}$
8 ft.	50.2656	25 $1\frac{1}{2}$	2	97.9347	35 $0\frac{7}{8}$
1	51.3178	25 $4\frac{5}{8}$	3	99.4021	35 $4\frac{1}{8}$
2	52.3816	25 $7\frac{7}{8}$	4	100.8797	35 $7\frac{1}{4}$
3	53.4562	25 11	5	102.3689	35 $10\frac{5}{8}$
4	54.5412	26 $2\frac{1}{8}$	6	103.8691	36 $1\frac{1}{2}$
5	55.6377	26 $5\frac{1}{4}$	7	105.3794	36 $4\frac{1}{2}$
6	56.7451	26 $8\frac{3}{8}$	8	106.9013	36 $7\frac{3}{4}$
7	57.8628	26 $11\frac{1}{2}$	9	108.4342	36 $10\frac{7}{8}$
8	58.9920	27 $2\frac{3}{4}$	10	109.9772	37 $2\frac{3}{4}$
9	60.1321	27 $5\frac{3}{4}$	11	111.5319	37 $5\frac{1}{4}$
10	61.2826	27 9	12 ft.	113.0976	37 $8\frac{3}{8}$
11	62.4445	28 $0\frac{1}{8}$	1	114.6732	37 $11\frac{1}{2}$
9 ft.	63.6174	28 $3\frac{1}{4}$	2	116.2607	38 $2\frac{5}{8}$
1	64.8006	28 $6\frac{3}{8}$	3	117.8590	38 $5\frac{3}{4}$
2	65.9951	28 $9\frac{1}{2}$	4	119.4674	38 $8\frac{7}{8}$
3	67.2007	29 $0\frac{5}{8}$	5	121.0876	39 0
4	68.4166	29 $3\frac{3}{4}$	6	122.7187	39 $3\frac{1}{4}$
5	69.6440	29 7	7	124.3598	39 $6\frac{3}{8}$
6	70.8823	29 $10\frac{1}{8}$	8	126.0127	39 $9\frac{1}{2}$
7	72.1309	30 $1\frac{1}{4}$	9	127.6765	40 $0\frac{5}{8}$
8	73.3910	30 $4\frac{3}{8}$	10	129.3504	40 $3\frac{3}{4}$
9	74.6620	30 $7\frac{1}{2}$	11	131.0360	40 $6\frac{7}{8}$
10	75.9433	30 $11\frac{5}{8}$	13 ft.	132.7326	40 10
11	77.2362	31 $1\frac{3}{4}$	1	134.4391	41 $1\frac{1}{8}$
10 ft.	78.5400	31 5	2	136.1574	41 $4\frac{3}{8}$
1	79.8540	31 $8\frac{1}{8}$	3	137.8867	41 $7\frac{1}{2}$
2	81.1795	31 $11\frac{1}{4}$	4	139.6260	41 $10\frac{5}{8}$
3	82.5160	32 $2\frac{3}{8}$	5	141.3771	42 $1\frac{5}{8}$
4	83.8627	32 $5\frac{1}{2}$	6	143.1391	42 $4\frac{7}{8}$
5	85.2211	32 $8\frac{5}{8}$	7	144.9111	42 8

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
8	146.6949	42 11⅛	10	222.5510	52 10⅓
9	148.4896	43 2¼	11	224.7603	53 1⅝
10	150.2943	43 5½	17 ft.	226.9806	53 4⅞
11	152.1109	43 8⅝	1	229.2105	53 8
14 ft.	153.9384	43 11¾	2	231.4525	53 11⅛
1	155.7758	44 2⅞	3	233.7055	54 2⅜
2	157.6250	44 6	4	235.9682	54 5⅝
3	159.4852	44 9⅛	5	238.2430	54 8½
4	161.3553	45 0¼	6	240.5287	54 11⅝
5	163.2373	45 3½	7	242.8241	55 2⅞
6	165.1303	45 6⅝	8	245.1316	55 6
7	167.0331	45 9¾	9	247.4500	55 9⅛
8	168.9479	46 0⅞	10	249.7781	56 0¼
9	170.8735	46 4	11	252.1184	56 3⅓
10	172.8091	46 7⅛	18 ft.	254.4696	56 6½
11	174.7565	46 11¼	1	256.8303	56 9⅝
15 ft.	176.7150	47 1½	2	259.2033	57 0⅞
1	178.6832	47 4⅝	3	261.5872	57 4
2	180.6634	47 7¾	4	263.9807	57 7⅛
3	182.6545	47 10⅞	5	266.3864	57 10¼
4	184.6555	48 2⅛	6	268.8031	58 1⅜
5	186.6684	48 5⅜	7	271.2293	58 4⅓
6	188.6923	48 8¼	8	273.6678	58 7⅝
7	190.7260	48 11⅝	9	276.1171	58 10¾
8	192.7716	49 2⅝	10	278.5761	59 2
9	194.8282	49 5¾	11	281.0472	59 5⅛
10	196.8946	49 8⅞	19 ft.	283.5294	59 8¼
11	198.9730	50 0	1	286.0210	59 11½
16 ft.	201.0624	50 3⅛	2	288.5249	60 2½
1	203.1615	50 6¼	3	291.0397	60 5⅝
2	205.2726	50 9⅜	4	293.5641	60 8¾
3	207.3946	51 0½	5	296.1107	60 11⅞
4	209.5264	51 3⅝	6	298.6483	61 3⅛
5	211.6703	51 6¾	7	301.2054	61 6¼
6	213.8251	51 10	8	303.7747	61 9⅜
7	215.9896	52 1⅛	9	306.3550	62 0½
8	218.1662	52 4¼	10	308.9448	62 3⅝
9	220.3537	52 7⅜	11	311.5469	62 6¾

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
20 ft.	314.1600	62 $9\frac{7}{8}$	2	421.5192	72 $9\frac{3}{8}$
1	316.7824	63 $1\frac{1}{8}$	3	424.5577	73 $0\frac{1}{2}$
2	319.4173	63 $4\frac{1}{4}$	4	427.6055	73 $3\frac{5}{8}$
3	322.0630	63 $7\frac{3}{8}$	5	430.6658	73 $6\frac{3}{4}$
4	324.7182	63 $11\frac{1}{2}$	6	433.7371	73 $9\frac{7}{8}$
5	327.3858	64 $1\frac{5}{8}$	7	436.8175	74 1
6	330.0643	64 $4\frac{3}{4}$	8	439.9106	74 $4\frac{1}{8}$
7	332.7522	64 $7\frac{7}{8}$	9	443.0146	74 $7\frac{1}{4}$
8	335.4525	64 11	10	446.1278	74 $10\frac{5}{8}$
9	338.1637	65 $2\frac{1}{4}$	11	449.2536	75 $1\frac{5}{8}$
10	340.8844	65 $5\frac{3}{8}$	24 ft.	452.3904	75 $4\frac{3}{4}$
11	343.6174	65 $8\frac{1}{4}$	1	455.5362	75 $7\frac{7}{8}$
21 ft.	346.3614	65 $11\frac{3}{8}$	2	458.6948	75 11
1	349.1147	66 $2\frac{3}{4}$	3	461.8642	76 $2\frac{1}{8}$
2	351.8804	66 $5\frac{1}{8}$	4	465.0428	76 $5\frac{1}{4}$
3	354.6571	66 9	5	468.2341	76 $8\frac{1}{2}$
4	357.4432	67 $0\frac{1}{4}$	6	471.4363	76 $11\frac{5}{8}$
5	360.2417	67 $3\frac{3}{8}$	7	474.6476	77 $2\frac{3}{4}$
6	363.0511	67 $6\frac{1}{2}$	8	477.8716	77 $5\frac{7}{8}$
7	365.8698	67 $9\frac{5}{8}$	9	481.1065	77 9
8	368.7011	68 $0\frac{3}{4}$	10	484.3506	78 $0\frac{1}{8}$
9	371.5432	68 $3\frac{7}{8}$	11	487.6073	78 $3\frac{1}{4}$
10	374.3947	68 7	25 ft.	490.8750	78 $6\frac{3}{8}$
11	377.2587	68 $10\frac{1}{4}$	1	494.1516	78 $9\frac{1}{2}$
22 ft.	380.1336	69 $1\frac{3}{8}$	2	497.4411	79 $0\frac{5}{8}$
1	383.0177	69 $4\frac{1}{2}$	3	500.7415	79 $3\frac{7}{8}$
2	385.9144	69 $7\frac{5}{8}$	4	504.0510	79 $7\frac{1}{8}$
3	388.8220	69 $10\frac{3}{4}$	5	507.3732	79 $11\frac{1}{2}$
4	391.7389	70 $1\frac{7}{8}$	6	510.7063	80 $1\frac{1}{4}$
5	394.6683	70 5	7	514.0484	80 $4\frac{3}{8}$
6	397.6087	70 $8\frac{1}{4}$	8	517.4034	80 $7\frac{3}{8}$
7	400.5583	70 $11\frac{1}{8}$	9	520.7692	80 $10\frac{3}{4}$
8	403.5204	71 $2\frac{1}{2}$	10	524.1441	81 $1\frac{1}{8}$
9	406.4935	71 $5\frac{5}{8}$	11	527.5318	81 5
10	409.4759	71 $8\frac{3}{4}$	26 ft.	530.9304	81 $8\frac{1}{8}$
11	412.4707	71 $11\frac{7}{8}$	1	534.3379	81 $11\frac{1}{4}$
23 ft.	415.4766	72 3	2	537.7583	82 $2\frac{3}{8}$
1	418.4915	72 $6\frac{1}{8}$	3	541.1896	82 $5\frac{1}{4}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	544.6299	82 $8\frac{5}{8}$	6	683.4943	92 $8\frac{1}{8}$
5	548.0830	82 $11\frac{7}{8}$	7	687.3598	92 $11\frac{1}{8}$
6	551.5471	83 3	8	691.2385	93 $2\frac{3}{8}$
7	555.0201	83 $6\frac{1}{8}$	9	695.1280	93 $5\frac{1}{2}$
8	558.5059	83 $9\frac{1}{4}$	10	699.0263	93 $8\frac{5}{8}$
9	562.0027	84 $0\frac{3}{8}$	11	702.9377	93 $11\frac{7}{8}$
10	565.5084	84 $3\frac{1}{2}$	30 ft.	706.8600	94 $2\frac{7}{8}$
11	569.0270	84 $6\frac{5}{8}$	1	710.7909	94 6
27 ft.	572.5566	84 $9\frac{7}{8}$	2	714.7350	94 $9\frac{1}{4}$
1	576.0949	85 1	3	718.6900	95 $0\frac{3}{8}$
2	579.6463	85 $4\frac{1}{4}$	4	722.6537	95 $3\frac{1}{2}$
3	583.2085	85 $8\frac{1}{8}$	5	726.6305	95 $6\frac{5}{8}$
4	586.7796	85 $11\frac{3}{8}$	6	730.6183	95 $9\frac{3}{4}$
5	590.3637	86 $1\frac{1}{2}$	7	734.6147	96 $0\frac{7}{8}$
6	593.9587	86 $4\frac{5}{8}$	8	738.6242	96 4
7	597.5625	86 $7\frac{7}{8}$	9	742.6447	96 $7\frac{1}{4}$
8	601.1793	86 11	10	746.6738	96 $10\frac{3}{8}$
9	604.8070	87 $2\frac{1}{8}$	11	750.7161	97 $1\frac{1}{2}$
10	608.4436	87 $5\frac{1}{4}$	31 ft.	754.7694	97 $4\frac{5}{8}$
11	612.0931	87 $8\frac{3}{8}$	1	758.8311	97 $7\frac{3}{4}$
28 ft.	615.7536	87 $11\frac{1}{2}$	2	762.9062	97 $10\frac{7}{8}$
1	619.4228	88 $2\frac{5}{8}$	3	766.9921	98 2
2	623.1050	88 $5\frac{3}{4}$	4	771.0866	98 $5\frac{1}{8}$
3	626.7982	88 9	5	775.1944	98 $8\frac{3}{8}$
4	630.5002	89 $0\frac{1}{8}$	6	779.3131	98 $11\frac{1}{2}$
5	634.2152	89 $3\frac{1}{4}$	7	783.4403	99 $2\frac{5}{8}$
6	637.9411	89 $6\frac{3}{8}$	8	787.5808	99 $5\frac{3}{4}$
7	641.6758	89 $9\frac{1}{2}$	9	791.7322	99 $8\frac{7}{8}$
8	645.4235	90 $0\frac{5}{8}$	10	795.8922	100 0
9	649.1821	90 $3\frac{3}{4}$	11	800.0654	100 $3\frac{1}{8}$
10	652.9495	90 $6\frac{7}{8}$	32 ft.	804.2496	100 $6\frac{3}{8}$
11	656.7300	90 $11\frac{1}{8}$	1	808.4422	100 $9\frac{1}{2}$
29 ft.	660.5214	91 $1\frac{1}{4}$	2	812.6481	101 $0\frac{5}{8}$
1	664.3214	91 $4\frac{3}{8}$	3	816.8650	101 $3\frac{3}{4}$
2	668.1346	91 $7\frac{1}{2}$	4	821.0904	101 $6\frac{7}{8}$
3	671.9587	91 $10\frac{5}{8}$	5	825.3291	101 10
4	675.7915	92 $1\frac{3}{4}$	6	829.5787	102 $1\frac{1}{8}$
5	679.6375	92 $4\frac{7}{8}$	7	833.8368	102 $4\frac{3}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
8	838.1082	102 $7\frac{1}{2}$	10	1008.4736	112 $6\frac{7}{8}$
9	842.3905	102 $10\frac{5}{8}$	11	1013.1705	112 10
10	846.6813	103 $1\frac{3}{4}$	36 ft.	1017.8784	113 $1\frac{1}{8}$
11	850.9855	103 $4\frac{7}{8}$	1	1022.5944	113 $4\frac{1}{4}$
33 ft.	855.3006	103 8	2	1027.3240	113 $7\frac{3}{8}$
1	859.6240	103 $11\frac{1}{8}$	3	1032.0646	113 $10\frac{3}{8}$
2	863.9609	104 $2\frac{1}{4}$	4	1036.8134	114 $1\frac{3}{4}$
3	868.3087	104 $5\frac{3}{8}$	5	1041.5758	114 $4\frac{7}{8}$
4	872.6649	104 $8\frac{3}{8}$	6	1046.3491	114 8
5	877.0346	104 $11\frac{3}{4}$	7	1051.1306	114 $11\frac{7}{8}$
6	881.4151	105 $2\frac{7}{8}$	8	1055.9257	115 $2\frac{1}{4}$
7	885.8040	105 6	9	1060.7317	115 $5\frac{3}{8}$
8	890.2064	105 $9\frac{1}{8}$	10	1065.5459	115 $9\frac{1}{4}$
9	894.6196	106 $0\frac{1}{4}$	11	1070.3738	115 $11\frac{3}{8}$
10	899.0413	106 $3\frac{3}{8}$	37 ft.	1075.2126	116 $2\frac{7}{8}$
11	903.4763	106 $6\frac{3}{8}$	1	1080.0594	116 6
34 ft.	907.9224	106 $9\frac{1}{4}$	2	1084.9201	116 $9\frac{1}{8}$
1	912.3767	107 $0\frac{7}{8}$	3	1089.7915	117 $0\frac{1}{4}$
2	916.8445	107 4	4	1094.6711	117 $3\frac{1}{2}$
3	921.3232	107 $7\frac{1}{8}$	5	1099.5644	117 $6\frac{1}{2}$
4	925.8103	107 $10\frac{1}{4}$	6	1104.4687	117 $9\frac{5}{8}$
5	930.3108	108 $1\frac{3}{8}$	7	1109.3810	118 $0\frac{3}{4}$
6	934.8223	108 $4\frac{3}{8}$	8	1114.3071	118 4
7	939.3421	108 $7\frac{3}{4}$	9	1119.2440	118 $7\frac{1}{8}$
8	943.8753	108 $10\frac{7}{8}$	10	1124.1891	118 $10\frac{1}{4}$
9	948.4195	109 2	11	1129.1478	119 $1\frac{3}{8}$
10	952.9720	109 $5\frac{1}{8}$	38 ft.	1134.1176	119 $4\frac{1}{2}$
11	957.5380	109 $8\frac{1}{4}$	1	1139.0953	119 $7\frac{3}{8}$
35 ft.	962.1150	109 $11\frac{3}{8}$	2	1144.0868	119 $10\frac{3}{4}$
1	966.7001	110 $2\frac{3}{8}$	3	1149.0892	120 2
2	971.2989	110 $5\frac{3}{4}$	4	1154.0997	120 $5\frac{1}{8}$
3	975.9085	110 $8\frac{7}{8}$	5	1159.1239	120 $8\frac{3}{8}$
4	980.5264	111 0	6	1164.1591	120 $11\frac{5}{8}$
5	985.1579	111 $3\frac{1}{8}$	7	1169.2023	121 $2\frac{1}{2}$
6	989.8003	111 $6\frac{1}{4}$	8	1174.2592	121 $5\frac{5}{8}$
7	994.4509	111 $9\frac{3}{8}$	9	1179.3271	121 $8\frac{3}{4}$
8	999.1151	112 $0\frac{1}{2}$	10	1184.4030	121 $11\frac{7}{8}$
9	1003.7902	112 $3\frac{3}{4}$	11	1189.4927	122 $3\frac{1}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
39 ft.	1194.5934	122 $6\frac{1}{4}$	2	1396.4619	132 $5\frac{5}{8}$
1	1199.7195	122 $9\frac{1}{2}$	3	1401.9880	132 $8\frac{3}{4}$
2	1204.8244	123 $0\frac{1}{2}$	4	1407.5219	132 $11\frac{7}{8}$
3	1209.9577	123 $3\frac{5}{8}$	5	1413.0698	133 3
4	1215.0990	123 $6\frac{3}{4}$	6	1418.6287	133 $6\frac{1}{8}$
5	1220.2542	123 $9\frac{7}{8}$	7	1424.1952	133 $9\frac{1}{4}$
6	1225.4203	124 $1\frac{1}{8}$	8	1429.7759	134 $0\frac{1}{2}$
7	1230.5943	124 $4\frac{1}{4}$	9	1435.3675	134 $3\frac{3}{8}$
8	1235.7822	124 $7\frac{5}{8}$	10	1440.9668	134 $6\frac{3}{4}$
9	1240.9810	124 $10\frac{1}{2}$	11	1446.5802	134 $9\frac{7}{8}$
10	1246.1878	125 $1\frac{5}{8}$	43 ft.	1452.2046	135 1
11	1251.4084	125 $4\frac{3}{4}$	1	1457.8365	135 $4\frac{1}{8}$
40 ft.	1256.6400	125 $7\frac{7}{8}$	2	1463.4827	135 $7\frac{1}{4}$
1	1261.8794	125 11	3	1469.1397	135 $10\frac{1}{2}$
2	1267.1327	126 $2\frac{1}{4}$	4	1474.8044	136 $1\frac{5}{8}$
3	1272.3970	126 $5\frac{3}{8}$	5	1480.4833	136 $4\frac{3}{4}$
4	1277.6692	126 $8\frac{1}{2}$	6	1486.1731	136 $7\frac{7}{8}$
5	1282.9553	126 $11\frac{5}{8}$	7	1491.8705	136 11
6	1288.2523	127 $2\frac{3}{4}$	8	1497.5821	137 $2\frac{1}{8}$
7	1293.5572	127 $5\frac{7}{8}$	9	1503.3046	137 $5\frac{1}{4}$
8	1298.8760	127 9	10	1509.0348	137 $8\frac{3}{8}$
9	1304.2057	128 $0\frac{1}{4}$	11	1514.7791	137 $11\frac{5}{8}$
10	1309.5433	128 $3\frac{3}{8}$	44 ft.	1520.5344	138 $2\frac{3}{4}$
11	1314.8949	128 $6\frac{1}{2}$	1	1526.2971	138 $5\frac{7}{8}$
41 ft.	1320.2574	128 $9\frac{5}{8}$	2	1532.0742	138 9
1	1325.6276	129 $0\frac{3}{4}$	3	1537.8622	139 $0\frac{1}{8}$
2	1331.0119	129 $3\frac{7}{8}$	4	1543.6578	139 $3\frac{1}{4}$
3	1336.4071	129 7	5	1549.4676	139 $6\frac{3}{8}$
4	1341.8101	129 $10\frac{1}{8}$	6	1555.2883	139 $9\frac{5}{8}$
5	1347.2271	130 $1\frac{3}{4}$	7	1561.1165	140 $0\frac{3}{4}$
6	1352.6551	130 $4\frac{1}{2}$	8	1566.9591	140 $3\frac{7}{8}$
7	1358.0908	130 $7\frac{5}{8}$	9	1572.8125	140 $7\frac{1}{2}$
8	1363.5406	130 $10\frac{3}{4}$	10	1578.6735	140 $10\frac{5}{8}$
9	1369.0012	131 $1\frac{7}{8}$	11	1584.5488	141 $1\frac{1}{4}$
10	1374.4697	131 5	45 ft.	1590.4350	141 $4\frac{3}{8}$
11	1379.9521	131 $8\frac{1}{8}$	1	1596.3286	141 $7\frac{1}{2}$
42 ft.	1385.4456	131 $11\frac{3}{8}$	2	1602.2366	141 $10\frac{3}{4}$
1	1390.2467	132 $2\frac{1}{2}$	3	1608.1555	142 $1\frac{7}{8}$

DIAMETERS, AREAS, ETC.—*Continued.*

Dia. in Feet & Inches.	Area in Feet.	Circum. in Feet & Inches.	Dia. in Feet & Ins.	Area in Feet.	Circum. in Feet & Inches.
4	1614.0819	142 5	9	1790.7610	150 0⅛
5	1620.0226	142 8⅛	10	1797.0145	150 3¼
6	1625.9743	142 11¼	11	1803.2826	150 6⅜
7	1631.9334	143 2⅜	48 ft.	1809.5616	150 9½
8	1637.9068	143 5½	1	1815.8477	151 0⅝
9	1643.8912	143 8¾	2	1822.1485	151 3¾
10	1649.8831	143 11⅞	3	1828.4602	151 6⅞
11	1655.8892	144 3	4	1834.7791	151 10⅛
46 ft.	1661.9064	144 6⅛	5	1841.1127	152 1¼
1	1667.9308	144 9¼	6	1847.4571	152 4⅜
2	1673.9698	145 0⅜	7	1853.8087	152 7½
3	1680.0196	145 3½	8	1860.1750	152 10⅝
4	1686.0769	145 6⅝	9	1866.5521	153 1¾
5	1692.1485	145 9⅞	10	1872.9365	153 4⅞
6	1698.2311	146 1⅛	11	1879.3355	153 8⅛
7	1704.3210	146 4⅛	49 ft.	1885.7454	153 11¼
8	1710.4254	146 7¼	1	1892.1724	154 2⅜
9	1716.5407	146 10⅜	2	1898.5041	154 5½
10	1722.6634	147 1½	3	1905.0367	154 8⅝
11	1728.8005	147 4⅝	4	1911.4965	154 11⅞
47 ft.	1734.9486	147 7¾	5	1917.9609	155 2⅞
1	1741.1039	147 11	6	1924.4263	155 6
2	1747.2738	148 2⅛	7	1930.9188	155 9¼
3	1753.4545	148 5¼	8	1937.3159	156 0⅛
4	1759.6426	148 8⅜	9	1943.9140	156 3½
5	1765.8452	148 11½	10	1950.4392	156 6⅝
6	1772.0587	149 2⅝	11	1956.9691	156 9¾
7	1778.2795	149 5⅞	50 ft.	1963.5000	157 0⅞
8	1784.5148	149 8⅞			

Table exhibiting the Temperatures and Volumes of Steam generated under different pressures.

Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.	Pressure in lbs. per square inch, atmospheric pressure included.	Temperature in degrees of Fahrenheit.	Volumes of steam compared with the volume of water.	Cubic inches of water in a cubic foot of steam.
15	213·0	1669	1·035	48	279.7	573	3·015
16	216·4	1572	1·099	49	281·0	562	3·074
17	219·6	1487	1·162	50	282·3	552	3·130
18	222·6	1410	1·226	51	283·6	542	3·188
19	225·6	1342	1·287	52	284·8	532	3·248
20	228·3	1280	1·350	53	286·0	523	3·304
21	231·0	1224	1·411	54	287·2	514	3·361
22	233·6	1172	1·474	55	288·4	506	3·415
23	236·1	1125	1·536	56	289·6	498	3·469
24	238·4	1082	1·597	57	290·7	490	3·526
25	240·7	1042	1·658	58	291·9	482	3·585
26	243·0	1005	1·719	59	293·0	474	3·645
27	245·1	971	1·779	60	294·1	467	3·700
28	247·2	939	1·840	61	294·9	460	3·756
29	249·2	909	1·910	62	295·9	453	3·814
30	251·2	882	1·959	63	297·0	447	3·865
31	253·1	855	2·021	64	298·1	440	3·927
32	255·0	831	2·079	65	299·1	434	3·981
33	256·8	808	2·138	66	300·1	428	4·037
34	258·6	786	2·198	67	301·2	422	4·094
35	260·3	765	2·258	68	302·2	417	4·143
36	262·0	746	2·316	69	303·2	411	4·204
37	263·7	727	2·376	70	304·2	406	4·256
38	265·3	710	2·433	71	305·1	401	4·309
39	266·9	693	2·493	72	306·1	396	4·363
40	268·4	677	2·552	73	307·1	391	4·419
41	269·9	662	2·610	74	308·0	386	4·476
42	271·4	647	2·679	75	308·9	381	4·535
43	272·9	634	2·725	76	309·9	377	4·583
44	274·3	620	2·787	77	310·8	372	4·645
45	275·7	608	2·842	78	311·7	368	4·695
46	277·1	596	2·899	79	312·6	364	4·747
47	278·4	584	2·958	80	313·5	359	4 812

Table by which to ascertain the amount of lap necessary on the steam side of a slide-valve to cut the steam off at various fractional parts of the stroke

To cut the steam off, after the piston has passed through						
$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{7}{8}$	$\frac{11}{12}$
of its stroke. Multiply the given stroke of the valve by						
·354	·323	·289	·250	·204	·177	144
and the product is the lap of the valve in terms of the stroke.						

Example.—Required the lap necessary to cut the steam off at the end of five-sixths of the stroke, the stroke of the valve being twelve inches, and without lead. $204 \times 12 = 2{\cdot}448$ inches.

As lead is not taken into account because of different quantities being required to different applications of the steam-engine, subtract from the lap half the lead; the remainder is the lap required. Thus, suppose the lead equal $\cdot 25 \div 2 = \cdot 125$ and $2{\cdot}448 - \cdot 125 = 2{\cdot}323$ inches, the lap with one-fourth inch of lead as given.

Table of the Mean Elastic Force of Steam in pounds per square inch, at various grades of Expansion.

Initial density of the steam in lbs. per square inch.	Dense steam cut off after the piston has passed through the following fractional parts of the stroke:						
	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{2}{5}$	$\frac{1}{2}$	$\frac{3}{5}$	$\frac{3}{4}$	$\frac{4}{5}$
9	4·69	5·37	6·89	7·62	8·13	8·67	8·80
10	5·22	5·97	7·67	8·46	9·03	9·64	9·78
11	5·74	6·56	8·43	9·31	9·94	10·60	10·76
12	6·26	7·16	9·19	10·16	10·84	11·57	11·74
13	6·78	7·75	9·96	11·01	11·75	12·53	12·72
14	7·31	8·53	10·73	11·85	12·65	13·49	13·97
15	7·83	8·95	11·49	12·69	13·55	14·46	14·68
16	8·35	9·54	12·26	13·54	14·46	15·42	15·66
17	8·87	10·14	13·03	14·39	15·36	16·38	16·63
18	9·39	10·74	13·79	15·24	16·27	17·35	17·61
19	9·92	11·33	14.56	16·81	17·17	18·31	18·59
20	10·44	11·93	15·33	16·93	18·07	19·28	19·57
25	13·04	14·91	19·16	21·16	22·59	24·09	24 46
30	15·65	17·89	22·99	25·39	27·11	28·91	29·35
35	18·26	20·88	26·83	29·63	31·63	33·73	34·24
40	20·87	23·86	30·66	33·86	36·15	38·55	39·14
45	23·48	26·84	34·88	38·09	40·66	43·37	44·03
50	26·09	29·82	38·32	42·33	45·18	48·19	48·92

Atmospheric pressure not included.

Example.—If dense steam be admitted to the cylinder of an engine at a pressure of 17 pounds per square inch, and cut off when the piston has moved through two-fifths of the stroke, the mean elastic pressure during the whole stroke will be 13·03 pounds per square inch, as obtained by initial density and expansive force.

Table by which to find the relative state of Piston and Exhaust after Expansion.

	Steam cut off at 1-3d from the end of the stroke.		Steam cut off at 1-4th from the end of the stroke.		Steam cut off at 1-6th from the end of the stroke		Steam cut off at 1-8th from the end of the stroke.	
Cover on the exhausting side of the valve in parts of the length of its stroke.	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut. (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port before it is shut (in parts of the stroke.)	Distance of the piston from the end of its stroke, when the exhausting-port behind it is opened (in parts of the stroke.)
1-8th	·178	·033	·143	·019	·109	·008	·093	·004
1-16th	·130	·060	·100	·040	·171	·022	·058	·015
1-32d	·113	·073	·085	·051	·058	·033	·043	·023
0	·029	·092	·067	·067	·043	·043	·038	·033

Example from the Table.—Suppose an engine with a stroke of six feet, or 72 inches, and the steam cut off when the piston is one-third from the end of its stroke, the cover on the exhaust side of the valve being 1-32d of its stroke, the relative positions will be the following:—

In a line with 1-32d and under 1-3d is ·113 and ·073; therefore $·113 \times 72 = 8·136$ inches the piston is from the end of the stroke, when the exhausting-port before the piston is shut, and $·073 \times 72 = 5·256$ inches the piston is from the end of the stroke, when the exhausting-port behind it is open

Table of Cylinders, with proportionate strokes for Steam-engines of nominal horse-power; the dense steam for Condensing Engines being seven pounds per square inch.

Stationary Condensing Engines.			Marine Condensing Engines.			High-pressure, or Non-condensing Engines.				
Horse-power.	Diameter of cylinders in inches.	Proportionate strokes in feet.	Horse-power.	Diameter of cylinders in inches.	Proportionate strokes in feet.	Horse-power.	Diameter of cylinders in inches, the force of the dense steam per square inch being 25 lbs.	30 lbs.	40 lbs.	50 lbs.
2	9	1¾	10	20	2	1	3¾	3½	3	2¾
3	11	2	12	21½	2	1½	4½	4¼	3⅝	3¼
4	12	2¼	15	23½	2¼	2	5¼	4¾	4¼	3¾
5	13½	2½	16	24½	2½	2½	5¾	5⅜	4⅝	4¼
6	14½	2¾	18	25¼	2½	3	6½	6	5	4½
8	16½	3	20	26½	2½	3½	6¾	6¼	5½	4⅝
10	18	3¼	25	28½	3	4	7½	6⅝	6	5¼
12	19½	3½	30	31½	3	4½	7¾	7⅛	6¼	5⅝
14	21	3½	35	33½	3¼	5	8¼	7½	6½	5¾
15	21½	3¾	40	36½	3¼	5½	8½	7⅞	6⅞	6⅛
16	22	4	45	37½	3½	6	9	8¼	7	6½
18	23	4¼	50	39½	3½	6½	9¼	8⅝	7½	6⅝
20	24½	4½	55	40½	4	7	9¾	9	7¾	6⅞
22	25¼	4½	60	43	4	7½	10	9¼	8	7¼
24	26½	4¾	65	44	4	8	10½	9¾	8¼	7½
25	26¾	5	70	46	4¼	8½	10¾	9⅞	8½	7⅝
26	27	5	75	46¾	4½	9	11¼	10½	8¾	7⅞
28	27½	5½	80	48	4½	10	11¾	11	9½	8½
30	28½	5½	85	49	4¾	11	12½	11⅜	9¾	8¾
35	30½	5¾	90	50	4¾	12	13	12	10½	9¼
40	32½	6	95	52	4¾	13	13¼	12¼	10⅞	9⅝
45	34¼	6	100	52½	5	14	14	12¾	11¼	10
50	36	6¼	110	55	5	15	14⅝	13⅛	11⅝	10¼
55	37½	6¼	115	56¼	5	16	15	13¾	12	10½
60	39	6½	120	57	5½	17	15¼	14	12½	10¾
65	40½	6½	125	58	5½	18	15¾	14½	12¾	11¼
70	41½	7	130	59	5½	19	16¼	14¾	13¼	11½
75	43	7	135	60	5¾	20	16¾	15¼	13½	11¾
80	44	7½	140	61	5¾	25	18½	17¼	15	13¼
85	45¼	7½	145	62	5¾	30	20¼	19¾	16¼	14½
90	46	8	150	62½	6	35	21½	20¼	17½	15½
95	47¼	8	175	67½	6	40	23	21⅜	18½	16¾
100	48½	8	200	71½	6½	Quantity of water for feed in gallons per minute to each horse-power, equal		·45	·5	·61 ·72
110	51	8	250	79½	6½					
120	52½	8½	260	81	6½					
130	54¼	9	270	81¾	7					
140	56	9	280	83	7					

Table of Nominal Velocities for the Pistons of Steam-engines, with given length of strokes

Stationary Condensing Engines.			Marine Engines.			High-pressure, or Non-condensing Engines.		
Length in feet and in.	Num. per min.	Velocity in feet per min.	Length in feet and in.	Num. per min.	Velocity in feet per min.	Length in feet and in.	Number per minute.	Velocity in feet per min.
1 9	46	161	2 0	42	168	1 0	80	160
2 0	42	168	2 3	39½	177¾	1 3	70	175
2 3	38	171	2 6	38	190	1 6	62	186
2 6	35	175	3 0	32	192	1 9	55	192½
2 9	32	176	3 3	29¾	193⅜	2 0	50	200
3 0	30	180	3 6	27¾	194¼	2 3	46	207
3 3	28½	185¼	4 0	24½	196	2 6	42½	212½
3 6	27	189	4 3	23½	199¾	2 9	39½	217¼
3 9	26	195	4 6	22½	202½	3 0	37	222
4 0	25	200	4 9	21½	204¼	3 3	35	228½
4 3	24	204	5 0	21	210	3 6	33	231
4 6	23	207	5 6	19½	214½	3 9	31	232½
5 0	21½	215	5 9	19	218½	4 0	29½	236
5 6	20	220	6 0	18½	222	4 6	27	243
6 0	19	228	6 6	17¼	224¼	5 0	24¾	247½
7 0	17½	245	7 0	16½	231	5 6	23	253
8 0	16	256	7 6	15½	232½	6 0	22	254

Table of Decimal Equivalents to Fractional Parts of Lineal Measures.

One inch, the integer or whole number.

·9375 = 7/8 and 1/16	·5625 = 1/2 and 1/16	·25 = 1/4
·875 = 7/8	·5 = 1/2	·1875 = 1/8 and 1/16
·8125 = 3/4 and 1/16	·4375 = 3/8 and 1/16	·125 = 1/8
·75 = 3/4	·375 = 3/8	·0625 = 1/16
·6875 = 5/8 and 1/16	·3152 = 1/4 and 1/16	·03125 = 1/32
·625 = 5/8		

One foot, or 12 inches the integer.

·9166 = 11 inches.	·4166 = 5 inches.	·0625 = 3/4 of inch.
·8338 = 10 "	·3333 = 4 "	·05208 = 5/8 "
·75 = 9 "	·25 = 3 "	·04166 = 1/2 "
·6666 = 8 "	·1666 = 2 "	·03125 = 3/8 "
·5833 = 7 "	·0833 = 1 "	·02083 = 1/4 "
·5 = 6 "	·07291 = 7/8 "	·1041 = 1/8 "

Table of Approximate Numbers, for various purposes.

Diameter of a circle	×	3·1416	= the circumference.
Circumference "	×	·31831	= the diameter.
Diameter "	×	·8862	= the side of an equal square.
Side of a square.....	×	1·128	= the diameter of an equal circle.
Square of diameter	×	·7854	= the area of a circle.
Square root of area	×	1·12837	= the diameter of equal circle.
Square of the diameter of a sphere	×	3·1416	= convex surface.
Cube of ditto.....	×	·5236	= solidity.
Diameter of a sphere	×	·806	= dimensions of equal cube.
Diameter of a sphere	×	·6667	= length of equal cylinder.
Square inches.....	×	·00695	= square feet.
Cubic inches.....	×	·00058	= cubic feet.
Cubic feet.....	×	·03704	= cubic yards
Cylindrical inches...	×	·0004546	= cubic feet.
Cylindrical feet	×	·02909	= cubic yards.
Cubic inches.....	×	·003607	= imperial gallons.
Cubic feet.....	×	·6232	= "
Cylindrical inches...	×	·002832	= "
Cylindrical feet	×	4·895	= "
183·346 circular inches.....			= 1 square foot.
2200 cylindrical inches.....			= 1 cubic foot.
Avoirdupois pounds	×	·009	= cwts.
Avoirdupois pounds	×	·00045	= tons.
Lineal feet.....	×	·00019	= English statute miles.
Lineal yards.....	×	·000568	= "

Table of Squares, Cubes, Square and Cube Roots of Numbers.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
1	1	1	1·0000000	1·0000000
8	4	2	1·4142136	1·2599210
27	9	3	1·7320508	1·4422496
64	16	4	2·0000000	1·5874011
125	25	5	2·2360680	1·7099759
216	36	6	2·4494897	1·8171216
343	49	7	2·6457513	1·9129312
512	64	8	2·8284271	2·0000000
729	81	9	3·0000000	2·0800837
1000	100	10	3·1622777	2·1544347
1331	121	11	3·3166248	2·2239801
1728	144	12	3·4641016	2·2894286
2197	169	13	3·6055513	2·3513347
2744	196	14	3·7416574	2·4101422
3375	225	15	3·8729833	2·4262121
4096	256	16	4·0000000	2·5198421
4913	289	17	4·1231056	2·6712816
5832	324	18	4·2426407	2·6207417
6859	361	19	4·3588989	2·6684016
8000	400	20	4·4721360	2·7144177
9261	441	21	4·5825757	2·7589243
10648	484	22	4·6904158	2·8020393
12167	529	23	4·7958315	2·8438670
13824	576	24	4·8989795	2·8844991
15625	625	25	5·0000000	2·9240177
17576	676	26	5·0990195	2·9624960
19683	729	27	5·1961524	3·0000000
21952	784	28	5·2915026	3·0365889
24389	841	29	5·3851648	3·0723168
27011	900	30	5·4772256	3·1072325
29791	961	31	5·5677644	3·1413806
32768	1024	32	5·6568542	3·1748021
35937	1089	33	5·7445626	3·2075343
39304	1156	34	5·8309519	3·2396118

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
42875	1225	35	5·9164798	3·2710663
46656	1296	36	6·0000000	3·3019272
50653	1369	37	6·0827625	3·3322218
54872	1444	38	6·1644140	3·3619754
59319	1521	39	6·2449980	3·3912114
64000	1600	40	6·3245553	3·4199519
68921	1681	41	6·4031242	3·4482172
74088	1764	42	6·4807407	3·4760266
79507	1849	43	6·5574385	3·5033981
85184	1936	44	6·6332496	3·5303483
91125	2025	45	6·7082039	3·5568933
97336	2116	46	6·7823300	3·5830479
103823	2209	47	6·8556546	3·6088261
110592	2304	48	6·9282032	3·6342411
117649	2401	49	7·0000000	3·6593057
125000	2500	50	7·0710678	3·6840314
132651	2601	51	7·1414284	3·7084298
140608	2704	52	7·2111026	3·7325111
148877	2809	53	7·2801099	3·7562850
157464	2916	54	7·3484692	3·7797631
166375	3025	55	7·4161985	3·8029525
175616	3136	56	7·4833148	3·8258624
185193	3249	57	7·5498344	3·8485011
195012	3364	58	7·6157731	3·8708766
205379	3481	59	7·6811457	3·8929965
216000	3600	60	7·7459667	3·9147632
226981	3721	61	7·8102497	3·9304972
238328	3844	62	7·8740079	3·9578915
250047	3969	63	7·9372539	3·9790571
262144	4096	64	8·0000000	4·0000000
274625	4225	65	8·0622577	4·0207256
287496	4356	66	8·1240384	4·0412401
300763	4489	67	8·1853528	4·0615480
314432	4624	68	8·2462113	4·0816551

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
328509	4761	69	8·3066239	4·1015661
343000	4900	70	8·3666003	4·1212853
357911	5041	71	8·4261498	4·1408178
373248	5184	72	8·4852814	4·1601676
389017	5329	73	8·5440037	4·1793390
405224	5476	74	8·6023253	4·1983364
421875	5625	75	8·6602540	4·2171633
438976	5776	76	8·7177979	4·2358286
456533	5929	77	8·7749644	4·2543210
474552	6084	78	8·8317609	4·2726586
493039	6241	79	8·8881944	4·2908404
512000	6400	80	8·9442799	4·3088695
531441	6561	81	9·0000000	4·3267487
551368	6724	82	9·0553851	4·3444815
571787	6889	83	9·1104336	4·3620707
592704	7056	84	9·1631514	4·3795191
614125	7225	85	9·2195445	4·3968296
636056	7396	86	9·2736185	4·4140049
658503	7569	87	9·3273791	4·4310476
681472	7744	88	9·3808315	4·4470692
704969	7921	89	9·4339811	4·4647451
729000	8100	90	9·4868330	4·4814047
753571	8281	91	9·5393920	4·4979414
778688	8464	92	9·5916630	4·5143574
804357	8649	93	9·6436508	4·5306549
830584	8836	94	9·6953597	4·5468359
857374	9025	95	9·7467943	4·5629026
884736	9216	96	9·7979590	4·5788570
912073	9409	97	9·8488578	4·5943009
949912	9604	98	9·8994949	4·6104363
970299	9801	99	9·9498744	4·6260650
1000000	10000	100	10·0000000	4·6415888
1030301	10201	101	10·0498756	4·6570095
1061228	10404	102	10·0995049	4·6723287

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
1092727	10609	103	10·1488916	4·6875482
1124864	10816	104	10·1980390	4·7026694
1157625	11025	105	10·2469508	4·7176940
1191016	11236	106	10·2956301	4·7326235
1225043	11449	107	10·3440804	4·7474594
1259712	11664	108	10·3923048	4·7622032
1295029	11881	109	10·4403065	4·7768562
1331000	12100	110	10·4880885	4·7914199
1367631	12321	111	10·5356538	4·8058995
1404928	12524	112	10·5830052	4·8202845
1442897	12769	113	10·6301458	4·8343881
1481344	12996	114	10·6770783	4·8488076
1520875	13225	115	10·7238053	4·8629442
1560896	13456	116	10 7703296	4·8769900
1601613	13689	117	10·8166538	4·8909732
1643032	13924	118	10·8627805	4·9048681
1685159	14161	119	10·9087121	4·9186847
1728000	14400	120	10·9544512	4·9324242
1771561	14641	121	11·0000000	4·9460874
1815848	14834	122	11·0453610	4·9596757
1860867	15129	123	11·0905365	4·9731898
1906624	15376	124	11·1355287	4·9866310
1953125	15625	125	11·1803399	5·0000000
2000376	15876	126	11·2249722	5·0132979
2048383	16129	127	11·2694277	5·0265257
2097152	16384	128	11·3137085	5·0396842
2146689	16641	129	11·3578167	5·0527743
2197000	16900	130	11·4017543	5·0657970
2248091	17161	131	11·4455231	5·0787531
2299968	17424	132	11·4891253	5·0916434
2352637	17689	133	11·5325626	5·1044687
2408104	17956	134	11·5758369	5·1172259
2460375	18225	135	11·6189500	5·1299278
2515456	18496	136	11·6619038	5·1425632

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
2571353	18769	137	11·7046999	5·1550367
2628072	19044	138	11·7473444	5·1676493
2685619	19321	139	11·7898261	5·1801015
2744000	19600	140	11·8321596	5·1924941
2803221	19881	141	11·8743421	5·2048279
2863288	20164	142	11·9163753	5·2171034
2924207	20449	143	11·9582607	5·2293315
2985984	20736	144	12·0000000	5·2414828
3048625	21025	145	12·0415946	5·2535879
3112136	21316	146	12·0830460	5·2656374
3176523	21609	147	12·1243557	5·2776321
3241792	21904	148	12·1655251	5·2895725
3307949	22211	149	12·2065556	5·3014592
3375000	22500	150	12·2474487	5·3132928
3442951	22801	151	12·2882057	5·3250740
3511008	23104	152	12·3288280	5·3368033
3581577	23409	153	12·3693169	5·3484812
3652264	23716	154	12·4096736	5·3601084
3723875	24025	155	12·4498996	5·3716854
3796416	24336	156	12·4899960	5·3832126
3869893	24649	157	12·5299641	5·3946907
3944312	24964	158	12·5698051	5·4061202
4019679	25281	159	12·6095202	5·4178015
4096000	25600	160	12·6491106	5·4258352
4173281	25921	161	12·6885775	5·4401218
4251528	26244	162	12·7279221	5·4513618
4330747	26569	163	12·7671453	5·4625556
4410944	26896	164	12·8062485	5·4737037
4492125	27225	165	12·8432326	5·4848066
4574296	27556	166	12·8840987	5·4958647
4657463	27889	167	12·9228480	5·5068784
4741632	28224	168	12·9614814	5·5178484
4826809	28561	169	13·0000000	5·5287748
4913000	28900	170	13·0384048	5·5396583

Table of Squares, Cubes, &c.—Continued.

Cubes.	Squares.	Number.	Square Roots.	Cube Roots.
5000211	29241	171	13·0766968	5·5504990
5088448	29584	172	13·1148770	5·5612578
5177717	29929	173	13·1529464	5·5720546
5268024	30276	174	13·1909060	5·5827702
5359375	30625	175	13·2287566	5·5934447
5451776	30976	176	13·2664992	5·6040787
5545233	31329	177	13·3041347	5·6146724
5639752	31684	178	13·3416641	5·6252263
5735339	32041	179	13·3790882	5·6357408
5832000	32400	180	13·4164079	5·6462162
5929741	32761	181	13·4536240	5·6566528
6028568	33124	182	13·4907376	5·6670511
6128487	33489	183	13·5277493	5·6774114
6229504	33856	184	13·5646600	5·6877340
6331625	34225	185	13·6014705	5·6980192
6434856	34596	186	13·6381817	5·7082675
6539203	34969	187	13·6747943	5·7184791
6644672	35344	188	13·7113092	5·7286543
6751260	35721	189	13·7477271	5·7387936
6859000	36100	190	13·7840488	5·7488971
6967871	36481	191	13·8202750	5·7589652
7077888	36864	192	13·8564065	5·7689982
7189517	37249	193	13·8924400	5·7789966
7301384	37636	194	13·9283883	5·7889604
7414875	38025	195	13·9642400	5·7988900
7529536	38416	196	14·0000000	5·8087857
7645373	38809	197	14·0356688	5·8186479
7762392	39204	198	14·0712473	5·8284867
7880599	39601	199	14·1067360	5·8382725
8000000	40000	200	14·1421356	5·8480355

Table of Hyperbolic Logarithms.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
1·01	·0099503	1·40	·3364722	1·79	·5822156
1·02	·0198026	1·41	·3435897	1·80	·5877866
1·03	·0295588	1·42	·3506568	1·81	·5933268
1·04	·0392207	1·43	·3576744	1·82	·5988365
1·05	·0487902	1·44	·3646431	1·83	6043159
1·06	·0582689	1·45	·3715635	1·84	·6097655
1·07	·0676586	1·46	·3784364	1·85	·6151856
1·08	·0769610	1·47	·3852624	1·86	·6205764
1·09	·0861777	1·48	·3920420	1·87	·6259384
1·10	·0953102	1·49	·3987761	1·88	·6312717
1·11	·1043600	1·50	·4054651	1·89	·6365768
1·12	·1133287	1·51	·4121096	1·90	·6418538
1·13	·1222176	1·52	·4187103	1·91	·6471032
1·14	·1310283	1·53	·4252677	1·92	·6523251
1·15	·1397619	1·54	·4317824	1·93	·6575200
1·16	·1484200	1·55	·4382549	1·94	·6626879
1·17	·1570037	1·56	·4446858	1·95	·6678293
1·18	·1655144	1·57	·4510756	1·96	·6729444
1·19	·1739533	1·58	·4574248	1·97	·6780335
1·20	·1823215	1·59	·4637340	1·98	·6830968
1·21	·1962030	1·60	·4700036	1·99	·6881346
1·22	·1988508	1·61	·4762341	2·00	·6931472
1·23	·2070141	1·62	·4824261	2·01	·6981347
1·24	·2151113	1·63	·4885800	2·02	·7030974
1·25	·2231435	1·64	·4946962	2·03	·7080357
1·26	·2341117	1·65	·5007752	2·04	·7129497
1·27	·2390169	1·66	·5068175	2·05	·7178397
1·28	·2468600	1·67	·5128236	2·06	·7227059
1·29	·2546422	1·68	·5187937	2·07	·7275485
1·30	·2623642	1·69	·5247285	2·08	·7323678
1·31	·2700271	1·70	·5306282	2·09	·7316470
1·32	·2776317	1·71	·5364933	2·10	·7419373
1·33	·2851789	1·72	·5423242	2·11	·7466879
1·34	·2926696	1·73	·5481214	2·12	·7514160
1·35	·3001045	1.74	·5538851	2·13	·7561219
1·36	·3074846	1·75	·5596157	2·14	·7608058
1·37	·3148107	1·76	·5653138	2·15	·7654678
1·38	·3220834	1·77	·5709795	2·16	·7701082
1·39	·3293037	1·78	·5766133	2·17	·7747271

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
2·18	·7793248	2·57	·9439058	2·96	1·0851892
2·19	·7839015	2·58	·9477893	2·97	1·0885619
2·20	·7884573	2·59	·9516578	2·98	1·0919233
2·21	·7929025	2·60	·9555114	2·99	1·0952733
2·22	·7975071	2·61	·9593602	3·00	1·0986123
2·23	·8021015	2·62	·9631743	3·01	1·1019400
2·24	·8064758	2·63	·9669838	3·02	1·1052568
2·25	·8109302	2·64	·9707789	3·03	1·1085626
2·26	·8153648	2·65	·9745596	3·04	1·1118575
2·27	·8197798	2·66	·9783261	3·05	1·1511415
2·28	·8241754	2·67	·9820784	3·06	1·1184149
2·29	·8285518	2·68	·9858167	3·07	1·1216775
2·30	·8329091	2·69	·9895411	3·08	1·1249295
2·31	·8372475	2·70	·9932517	3·09	1·1281710
2·32	·8415671	2·71	·9969486	3·10	1·1314021
2·33	·8458682	2·72	1·0006318	3·11	1·1346227
2·34	·8501509	2·73	1·0043015	3·12	1·1378330
2·35	·8544153	2·74	1·0079579	3·13	1·1410330
2·36	·8586616	2·75	1·0116008	3·14	1·1442227
2·37	·8628899	2·76	1·0152306	3·15	1·1474024
2·38	·8671004	2·77	1·0188473	3·16	1·1505720
2·39	·8712933	2·78	1·0224509	3·17	1·1537315
2·40	·8754687	2·79	1·0260415	3·18	1·1568811
2·41	·8796267	2·80	1·0296194	3·19	1·1600209
2·42	·8837675	2·81	1·0331844	3·20	1·1631508
2·43	·8878912	2·82	1·0367368	3·21	1·1662709
2·44	·3919980	2·83	1·0402766	3·22	1·1693813
2·45	·8960880	2·84	1·0438040	3·23	1·1724821
2·46	·9001613	2·85	1·0473189	3·24	1·1755733
2·47	·9042181	2·86	1·0508216	3·25	1·1786549
2·48	·9082585	2·87	1·0543120	3·26	1·1817271
2·49	·9122826	2·88	1·0577902	3·27	1·1847899
2·50	·9162907	2·89	1·0612564	3·28	1·1878434
2·51	·9202827	2·90	1·0647107	3·29	1·1908875
2·52	·9242589	2·91	1·0681530	3·30	1·1939224
2·53	·9282193	2·92	1·0715836	3·31	1·1969481
2·54	·9321640	2·93	1·0750024	3·32	1·1999647
2·55	·9360933	2·94	1·0784095	3·33	1·2029722
2·56	·9400072	2·95	·0818051	3·34	1·2059707

Table of Hyperbolic Logarithms—Continue l.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
3·35	1·2089603	3·74	1·3190856	4·13	1·4182774
3·36	1·2119409	3·75	1·3217558	4·14	1·4206957
3·37	1·2149127	3·76	1·3244189	4·15	1·4231083
3·38	1·2178757	3·77	1·3271749	4·16	1·4255150
3·39	1·2208299	3·78	1·3297240	4·17	1·4279160
3·40	1·2237754	3·79	1·3323660	4·18	1·4323112
3·41	1·2267122	3·80	1·3350010	4·19	1·4327007
3·42	1·2296405	3·81	1 3376291	4·20	1·4350845
3·43	1·2325605	3·82	1·3402504	4·21	1·4374626
3·44	1·2354714	3·83	1·3428648	4·22	1·4398351
3·45	1·2387420	3·84	1·3454723	4·23	1·4422020
3·46	1·2412685	3·85	1·3480731	4·24	1·4445632
3·47	1·2441545	3·86	1·3506671	4·25	1·4469189
3·48	1·2470322	3·87	1·3532544	4·26	1·4492691
3·49	1·2499017	3·88	1·3558351	4·27	1·4516138
3·50	1·2527629	3·89	1·3584091	4·28	1·4539530
3·51	1·2556160	3·90	1·3609765	4·29	1·4562867
3·52	1·2584609	3·91	1·3635373	4·30	1·4586149
3·53	1·2612978	3·92	1·3660916	4·31	1·4609379
3·54	1·2641266	3·93	1·3686394	4·32	1·4632553
3·55	1·2669475	3·94	1·3711807	4·33	1·4655635
3·56	1·2697605	3·95	1·3737156	4·34	1·4678743
3·57	1·2725655	3·96	1·3726440	4·35	1 4701758
3·58	1·2753627	3·97	1·3787661	4·36	1·4724720
3·59	1·2781521	3·98	1·3812818	4·37	1·4747630
3·60	1·2809338	3·99	1·3837912	4·38	1·4778487
3·61	1·2837077	4·00	1·3862943	4·39	1·4793292
3·62	1·2864740	4·01	1·3887912	4·40	1·4816045
3·63	1·2892326	4·02	1·3912818	4·41	1·4838746
3·64	1·2919836	4·03	1 3937663	4·42	1·4838746
3·65	1·2947271	4·04	1·3962446	4·43	1·4883995
3·66	1·2974631	4·05	1·3987168	4·44	1·4906543
3·67	1·3001916	4 06	1·4011829	4·45	1·4929040
3·68	1·3029127	4·07	1 4036429	4·46	1·4914870
3·69	1·3056264	4·08	1·4060969	4·47	1·4973883
3·70	1·3083328	4·09	1·4085449	4·48	1·4996230
3·71	1·3110318	4·10	1·4109869	4·49	1·5018527
3·72	1·3137236	4·11	1·4134230	4·50	1 5040774
3·73	1·3164082	4·12	1·4158531	4·51	1·5062971

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
4·52	1·5085119	4·91	1·5912739	5·30	1·6677068
4·53	1·5107219	4·92	1·5933085	5·31	1·6695918
4·54	1·5129269	4·93	1·5953389	5·32	1·6714733
4·55	1·5151272	4·94	1·5973653	5·33	1·6733512
4·56	1·5173226	4·95	1·5993875	5·34	1·6752256
4·57	1·5195132	4·96	1·6014057	5·35	1·6770965
4·58	1·5216990	4·97	1·6034198	5·36	1·6789639
4·59	1·5238800	4·98	1·6054298	5·37	1·6808278
4·60	1·5260563	4·99	1·6074358	5·38	1·6826882
4·61	1·5282278	5·00	1·6094379	5·39	1·6845453
4·62	1·5303947	5·01	1·6114359	5·40	1·6863989
4·63	1·5325568	5·02	1·6134300	5·41	1·6882491
4·64	1·5347143	5·03	1·6154200	5·42	1·6900958
4·65	1·5368672	5·04	1·6174060	5·43	1·6919391
4·66	1·5390154	5·05	1·6193882	5·44	1·6937790
4·67	1·5411590	5·06	1·6213664	5·45	1·6956155
4·68	1·5432981	5·07	1·6233408	5·46	1·6974487
4·69	1·5454325	5·08	1·6253112	5·47	1·6992786
4·70	1·5475625	5·09	1·6272778	5·48	1·7011051
4·71	1·5496879	5·10	1·6292405	5·49	1·7029282
4·72	1·5518087	5·11	1·6311994	5·50	1·7047481
4·73	1·5539252	5·12	1·6331544	5·51	1·7065646
4·74	1·5560371	5·13	1·6351056	5·52	1·7083778
4·75	1·5581446	5·14	1·6370530	5·53	1·7101878
4·76	1·5602476	5·15	1·6389967	5·54	1·7119944
4·77	1·5623462	5·16	1·6409365	5·55	1·7137979
4·78	1·5644405	5·17	1·6428726	5·56	1·7155981
4·79	1·5665304	5·18	1·6448050	5·57	1·7173950
4·80	1·5686159	5·19	1·6463336	5·58	1·7191887
4·81	1·5706971	5·20	1·6486586	5·59	1·7209792
4·82	1·5727739	5·21	1·6505798	5·60	1·7227666
4·83	1·5748464	5·22	1·6524974	5·61	1·7245507
4·84	1·5769147	5·23	1·6544112	5·62	1·7263316
4·85	1·5789787	5·24	1·6563214	5·63	1·7281004
4·86	1·5810384	5·25	1·6582280	5·64	1·7298840
4·87	1·5830939	5·26	1·6601310	5·65	1·7316555
4·88	1·5851452	5·27	1·6620303	5·66	1·7334238
4·89	1·5870923	5·28	1·6639260	5·67	1·7351891
4·90	1·5892352	5·29	1·6658182	5·68	1·7369512

Table of Hyperbolic Logarithms—Continued.

Number.	Logarithms.	Number.	Logarithms.	Number.	Logarithms.
5·69	1·7387102	5·93	1·7800242	6·17	1·8196988
5·70	1·7404661	5·94	1·7817091	6·18	1·8213182
5·71	1·7422189	5·95	1·7833112	6·19	1·8229351
5·72	1·7439687	5·96	1·7850704	6·20	1·8245103
5·73	1·7457155	5·97	1·7867469	6·21	1·8261608
5·74	1·7474591	5·98	1·7884205	6·22	1·8277639
5·75	1·7491998	5·99	1·7900914	6·23	1·8293763
5·76	1·7509374	6·00	1·7917594	6·24	1·8309801
5·77	1·7526720	6·01	1·7934247	6·25	1·8325814
5·78	1·7544036	6·02	1·7950872	6·26	1·8341801
5·79	1·7561323	6·03	1·7967470	6·27	1·8357763
5·80	1·7578579	6·04	1·7984040	6·28	1·8373699
5·81	1·7595805	6·05	1·8000582	6·29	1·8389610
5·82	1·7613002	6·06	1·8017098	6·30	1·8405496
5·83	1·7630170	6·07	1·8033586	6·31	1·8421356
5·84	1·7647380	6·08	1·8050047	6·32	1·8437191
5·85	1·7664416	6·09	1·8066481	6·33	1·8453002
5·86	1·7681496	6·10	1·8082887	6·34	1·8468787
5·87	1·7698546	6·11	1·8099267	6·35	1·8484547
5·88	1·7715567	6·12	1·8115621	6·36	1·8500283
5·89	1·7732559	6·13	1·8131947	6·37	1·8515994
5·90	1·7749523	6·14	1·8148247	6·38	1·8531680
5·91	1·7766458	6·15	1·8164520	6·39	1·8547342
5·92	1·7783364	6·16	1·8180767	6·40	1·8562979

Table of Natural Sines, Co-sines, Tangents, Co-tangents, Secants and Co-secants to every degree of the Quadrant.

Deg.	Sines.	Co-sines.	Tangents	Co-tangents.	Secants.	Co-secants	Deg.
0	·00000	1·00000	·00000	Infinite	1·00000	Infinite	90
1	·01745	·99985	·01746	57·2900	1·00015	57·2987	89
2	·03490	·99939	·03492	28·6363	1·00061	28·6537	88
3	·05234	·99863	·05241	19·0811	1·00137	19·1073	87
4	·06976	·99756	·06993	14·3007	1·00244	14·3356	86
5	·08716	·99619	·08749	11·4301	1·00382	11·4737	85
6	·10453	·99452	·10510	9·51236	1·00551	9·56677	84
7	·12187	·99255	·12278	8·14435	1·00751	8·20551	83
8	·13917	·99027	·14054	7·11537	1·00983	7·18530	82
9	·15643	·98769	·15836	6·31375	1·01246	6·39245	81
10	·17365	·98481	·17633	5·67128	1·01543	5·75877	80
11	·19081	·98163	·19438	5·14455	1·01872	5·24084	79
12	·20791	·97815	·21256	4·70463	1·02234	4·80973	78
13	·22495	·97437	·23087	4·33148	1·02630	4·44541	77
14	·24192	·97030	·24933	4·01078	1·03061	4·13356	76
15	·25882	·96593	·26795	3·73205	1·03588	3·86370	75
16	·27564	·96126	·28675	3·48741	1·04030	3·62796	74
17	·29237	·95630	·30573	3·27085	1·04569	3·42030	73
18	·30902	·95106	·32492	3·07768	1·05146	3·23607	72
19	·32557	·94552	·34433	2·90421	1·05762	3·07155	71
20	·34202	·93969	·36397	2·74748	1·06418	2·92380	70
21	·35837	·93358	·38386	2·60509	1·07114	2·79043	69
22	·37461	·92718	·40403	2·47509	1·07853	2·66947	68
23	·39073	·92060	·42447	2·35585	1·08636	2·55930	67
24	·40674	·91355	·44523	2·24004	1·09464	2·45859	66
25	·42262	·90631	·46631	2·14451	1·10338	2·36620	65
26	·43837	·89879	·48773	2·05030	1·11260	2·28117	64
27	·45399	·89101	·50952	1·96261	1·12233	2·20869	63
28	·46947	·88295	·53171	1·88073	1·13257	2·13005	62
29	·48481	·87462	·55431	1·80105	1·14335	2·06266	61
30	·50000	·86603	·57735	1·73205	1·15470	2·00000	60
31	·51504	·85717	·60086	1·66428	1·16663	1·94160	59
32	·52992	·84805	·62487	1·60033	1·17918	1·88708	58
33	·54464	·83867	·64941	1·53986	1·19236	1·83608	57
34	·55919	·82904	·67451	1·48256	1·20622	1·78829	56
35	·57358	·81915	·70021	1·42815	1·22077	1·74345	55
36	·58778	·80902	·72654	1·37638	1·23607	1·70130	54
37	·60181	·79863	·75355	1·32704	1·25214	1·66164	53
38	·61566	·78801	·78129	1·27994	1·26902	1·62427	52
39	·62932	·77715	·80978	1·23490	1·28676	1·58902	51
40	·64279	·76604	·83910	1·19175	1·30541	1·55572	50
41	·65606	·75471	·86929	1·15037	1·32611	1·52425	49
42	·66993	·74314	·90040	1·11061	1·34561	1·49448	48
43	·68200	·73135	·93251	1·07237	1·36706	1·46628	47
44	·69466	·71934	·96569	1·03553	1·39012	1·43956	46
45	·70711	·70711	1·00000	1·00000	1·41421	1·41421	45

Table of the Expansion of Air by Heat, that at 32° *Fahrenheit being* 1·000.

Fah.	Volume.	Fah.	Volume.	Fah.	Volume.
35° ...	1·007	85° ...	1·121	170° ...	1·295
40 ...	1·021	90 ...	1·132	180 ...	1·315
45 ...	1·032	95 ...	1·142	190 ...	1·334
50 ...	1·043	100 ...	1·152	200 ...	1·364
55 ...	1·055	110 ...	1·173	210 ...	1·372
60 ...	1·066	120 ...	1·194	212 ...	1·376
65 ...	1·077	130 ...	1·215	302 ...	1·558
70 ..	1·089	140 ...	1·235	392 ...	1·739
75 .	1·099	150 ...	1·255	482 ...	1·919
80 .	1·110	160 ...	1·275	572 ...	2·098

NOTE.—One hundred parts of pure air by weight contain 75 55 parts of nitrogen, 23·32 parts oxygen, and 1·3 carbonic acid, and watery vapour.

The weight or pressure of the atmosphere equal a column of water 34 feet in height, or a column of mercury 30 inches in height, or 14·7 pounds per square inch at a mean temperature.

The resistance of air increases as the square of the velocity, and the resistance per square foot as the velocity multiplied by ·002288.

Table of the Relative Indications of Barometer and Thermometer at the boiling points of Fresh Water.

When the Barometer indicates 30 inches, the boiling point is 212° Fah., and 0·589 of barometric pressure corresponds to a difference of 1° Fah.

Columns of Fresh Water in feet equal to columns of Mercury in inches.	Barometer, Height of Mercury in inches.	Thermometer, Degrees of Fahrenheit.
35·07	31	213·57
34·50	30·5	212·79
34·02	30	212·00
33·37	29·5	211·20
32·81	29	210·38
32·22	28·5	209·55
31·84	28	208·69
31·11	27·5	207·84
30·52	27	206·96
	In a vacuum, water boils at	98·00 to 100

To find the height of a mountain by the Barometer.

Rule 1.—Multiply the difference between 32° Fah. and the mean temperature of the air by ·21, and add the product to 87 if the mean temperature be above 32°, but subtract it if below.

Rule 2.—Multiply the sum or difference as found above by thirty times the difference between the barometric heights in tenths of inches, and divide the product by the mean of the barometric heights; the quotient is the approximated elevation

Rule 3.—Multiply the difference between the mercurial temperatures by 2·833 feet, and add the product to the approximated elevation if that of the upper barometer be the greatest, otherwise subtract it; the result will be the corrected elevation in English feet.

Table of Specific Gravities.

Metals.	Weight, water being 1000.	Number of cubic inches in a pound.	Weight of a cubic inch in pounds.
Platina	19500	1·417	·7053
Pure gold	19258	1·435	·6965
Mercury	13560	2·04	·4902
Lead	11352	2·435	·4105
Pure silver	10474	2·638	·3788
Bismuth	9823	2·814	·3552
Copper	8788	3·146	·3178
Brass	7824	3·533	·3036
Iron, cast	7264	3·806	·263
Iron, bar	7700	3·592	·279
Steel	7833	3·530	·2833
Tin	7291	3·790	·2636
Zinc	7190	3·845	·26

Various Bodies.	Weight, water being 1000.	Weight of a cubic foot in pounds.	Number of cubic feet in a ton.
Marble, average	2720	170·0	13
Granite, do.	2651	165·6	13·5
Chalk, British	2781	173·8	12·75
Brick, red, common	2160	135·0	17·5
Brick, fire, Welsh	2408	150·5	14·5
Tallow, average	942	59·0	38·0
Ice, from fresh water	1001	53·0	35·5
Coal, Welsh	1526	95·3	24·7
Coal, Lancashire	1319	82·4	26·0
Coal, Scotch	1300	81·5	27·5
Coal, cannel	1272	79·5	28·0
Coal, Newcastle	1270	79·3	28·2
Coke, dry	755	47·0	47·6

Table of Specific Gravities—Continued.

Timber, Seasoned	Weight, water being 1000.	Weight of a cubic foot in pounds.	Number of cubic feet in a ton.
English oak	934	58	38·5
African oak	944	59	38·0
Riga oak	872	54	41·5
Beach oak	852	48	45·0
Ash oak	845	52	43·0
Mahogany, Spanish . .	800	50	45·0
Dantzic oak	756	47	48·0
Riga fir	753	47	48·0
Maple	752	47	47·5
Teak	750	46	48·5
Elm	673	42	53·0
American oak . . .	672	42	53·0
Walnut	671	41·9	53·5
Pitch pine	660	41	54·5
Red pine	657	47	54·5
Poona	640	40	55·0
Mahogany, Honduras .	637	40	55·0
Sycamore	604	38	59.0
Lime-tree	600	37	59·5
Cedar	561	35	64·0
Yellow pine	461	28	80·0
Cork	240	15	149·0
Pine, white	426	26	84·2

Table of Specific Gravities—Continued.

Liquids.	Weight, water being 1000.	Weight of an imp. gallon in pounds.
Water from the Dead Sea . . .	1240	12·4
Water from the Mediterranean .	1029	10·3
Water from the Irish Channel .	1028	10·2
Water from the Baltic	1015	10·2
Vinegar	1010	10·1
Turpentine	991	9·8
Linseed oil	940	9·4
Whale oil	923	9·2
Proof spirit	922	9·2
Rape-seed oil	919	9·3
Olive oil	915	9·2
Alcohol, com.	837	8·3

Names of Gases, Atmospheric Air being 1000.	
Carbonic acid gas	1527
Oxygen	1111
Carburetted hydrogen	972
Nitrogen	969
Steam of water at 212°	623
Chlorine	470
Hydrogen	69

Table of the Weight of Bar Iron.

ROUND.					
Diameter in inches.	Length, one foot.		Diameter in inches.	Length, one foot.	
	Weight in pounds.	Weight in pounds.		Weight in pounds.	Weight in pounds.
$\frac{1}{4}$	·164	·0137	$3\frac{1}{8}$	25·620	2·135
$\frac{5}{16}$	·256	·0233	$3\frac{1}{4}$	27·709	2·309
$\frac{3}{8}$	·369	·0307	$3\frac{3}{8}$	29·881	2·490
$\frac{7}{16}$	·503	·0420	$3\frac{1}{2}$	32·170	2·681
$\frac{1}{2}$	·656	·0547	$3\frac{5}{8}$	34·472	2·873
$\frac{9}{16}$	·831	·0692	$3\frac{3}{4}$	36·895	3·075
$\frac{5}{8}$	1·025	·0854	$3\frac{7}{8}$	39·390	3·283
$\frac{11}{16}$	1·241	·1034	4 in.	41·984	3·499
$\frac{3}{4}$	1·476	·1230	$4\frac{1}{8}$	44·637	3·720
$\frac{13}{16}$	1·732	·1443	$4\frac{1}{4}$	47·385	3·949
$\frac{7}{8}$	2·011	·1676	$4\frac{1}{2}$	53·132	4·428
$\frac{15}{16}$	2·306	·1921	$4\frac{3}{4}$	59·187	4 932
1 in.	2·624	·2187	5 in.	65·585	5·465
$1\frac{1}{8}$	3·321	·2767	$5\frac{1}{4}$	72·618	6·051
$1\frac{1}{4}$	4·099	·3146	$5\frac{1}{2}$	79 370	6·614
$1\frac{3}{8}$	4·961	·4134	$5\frac{3}{4}$	86·731	7·227
$1\frac{1}{2}$	5 913	·4927	6 in.	94·610	7·884
$1\frac{5}{8}$	6 928	·5773	$6\frac{1}{2}$	110·84	9·237
$1\frac{3}{4}$	8·043	·6702	7 in.	128 68	10·723
$1\frac{7}{8}$	9·224	·7686	$7\frac{1}{2}$	147·58	12·298
2 in.	10·496	·8747	8 in.	167·94	13·995
$2\frac{1}{8}$	11·846	·9872	$8\frac{1}{2}$	189·54	15·795
$2\frac{1}{4}$	13·283	1·107	9 in.	212 53	17·710
$2\frac{3}{8}$	14·797	1·233	$9\frac{1}{2}$	236·75	19·729
$2\frac{1}{2}$	16·396	1·366	10 in.	262·34	21·861
$2\frac{5}{8}$	18·146	1·512	$10\frac{1}{2}$	290·47	24·206
$2\frac{3}{4}$	19·842	1·653	11 in.	317·48	26·457
$2\frac{7}{8}$	21·684	1·307	$11\frac{1}{2}$	346·93	28·911
3 in.	23·653	1·971	12 in.	378·44	31·537

Table of the Weight of Bar Iron—Continued.

SQUARE.					
Side of square in inches.	Length, one foot.		Side of square in inches.	Length, one foot.	
	Weight in pounds.	Weight in pounds.		Weight in pounds.	Weight in pounds.
$\frac{1}{4}$	·209	·0174	$2\frac{1}{8}$	15·083	1·257
$\frac{3}{8}$	·470	·0391	$2\frac{1}{4}$	16·909	1·409
$\frac{1}{2}$	·835	·0696	$2\frac{3}{8}$	18·840	1·570
$\frac{5}{8}$	1·305	·1087	$2\frac{1}{2}$	20·875	1·739
$\frac{3}{4}$	1·879	·1565	$2\frac{5}{8}$	23·115	1·926
$\frac{7}{8}$	2·558	·2131	$2\frac{3}{4}$	25·259	2·105
1 in.	3·340	·2783	$2\frac{7}{8}$	27·608	2·301
$1\frac{1}{8}$	4·228	·3523	3 in.	30·070	2·506
$1\frac{1}{4}$	5·219	·4349	$3\frac{1}{4}$	35·279	2·940
$1\frac{3}{8}$	6·315	·5262	$3\frac{1}{2}$	40·916	3·409
$1\frac{1}{2}$	7·516	·6263	$3\frac{3}{4}$	46·969	3·914
$1\frac{5}{8}$	8·820	·7350	4 in.	53·440	4·455
$1\frac{3}{4}$	10·229	·8524	$4\frac{1}{2}$	67·637	5·636
$1\frac{7}{8}$	11·743	·9786	5 in.	83·510	6·959
2 in.	13·360	1·113			

Weight of a Lineal Foot of Common Angle Iron, for the construction of Steam Boilers, &c.

Breadth in inches.	Weight in pounds.	Breadth in inches.	Weight in pounds.
3	10·4	2	3·9
$2\frac{3}{4}$	8·3	$1\frac{3}{4}$	3·3
$2\frac{1}{2}$	6·5	$1\frac{1}{2}$	2·7
$2\frac{1}{4}$	5·0		

TABLE OF THE WEIGHT OF FLAT BAR, HOOP, PLATE, AND SHEET IRON.

Weight of a Lineal Foot of Flat Bar and Hoop Iron in pounds.

Thickness in inches.	Breadth in inches.										
	2½	3	2¾	2½	2¼	2	1¾	1½	1¼	1	¾
⅛	1·47	1·26	1·15	1·05	·094	·084	·073	·063	·052	·042	·031
3-16	2·20	1·89	1·73	1·57	1·41	1·26	1·10	·094	·078	·063	·047
¼	2·94	2·52	2·31	2·10	1·89	1·68	1·47	1·26	1·05	·084	·063
⅜	4·41	3·78	3·46	3·15	2·83	2·52	2·20	1·89	1·57	1·26	·094
½	5·88	5·04	4·62	4·20	3·78	3·36	2·94	2·22	2·10	1·68	1·26
⅝	7·35	6·30	5·77	5·25	4·72	4·20	3·67	3·15	2·62	2·10	1·57
¾	8·82	7·56	6·93	6·30	5·66	5·04	4·41	3·78	3·15	2·52	
⅞	10·29	8·82	8·08	7·35	6·61	5·88	5·14	4.41	3·67	2·94	
1 in.	11·76	10·08	9·24	8·40	7·56	6·72	5·87	5·04	4·20		

Weight of a Square Foot of Plate Iron in pounds.

Thickness in parts of an inch.	⅛	3/16	¼	5/16	⅜	7/16	½	9/16	⅝	11/16	¾
Weight in pounds.	5	7½	10	12½	15	17½	20	22½	25	27½	30

Weight of Square Foot of Sheet Iron in pounds.

Number on wire gauge, and weight in pounds.	1	2	3	4	5	6	7	8	9	10	11
	12·5	12	11	10	9	8	7·5	7	6	5·68	5
Number on wire gauge, and weight in pounds.	12	13	14	15	16	17	13	19	20	21	22
	4·62	4·32	4	3·95	3	2·5	2·18	1·93	1·62	1·5	1·37

Weight of a Square Foot of Sheet and Plate Copper in pounds.

Number on wire gauge, and weight in pounds.	12	13	14	15	16	17	18	19	20	21	22
	5·08	4·34	3·60	3·27	2·90	2·52	2·15	1·97	1·78	1·62	1·45
Thickness in parts of an inch.	5/32	3/16	7/32	¼	9/32	5/16	11/32	⅜	13/32	7/16	½ in.
Weight in pounds.	7·26	8·71	10·16	11·61	13·07	14·52	15·97	17·41	18·87	20·32	23·22

NOTE.—The weight of plate or sheet iron being 1. The weight of brass equals 1·09, and the weight of lead 1·48.

ENGLISH STANDARD MEASURES.

LINEAL MEASURE.

12 inches	= 1 foot.
3 feet	= 1 yard.
1760 yards, or 5280 feet	= 1 statute mile.
7·92 inches	= 1 link.
100 links, or 22 yards	= 1 chain.
80 chains	= 1 statute mile

SQUARE MEASURE.

144 square inches	= 1 square foot.
9 square feet	= 1 square yard.
4840 square yards	= 1 acre.
62·7264 square inches	= 1 square link.
10000 square links	= 1 square chain
10 square chains	= 1 acre.

CUBIC MEASURE.

1728 cubic inches	= 1 cubic foot.
27 cubic feet	= 1 cubic yard.

LIQUID MEASURE.

8·665 cubic inches	= 1 gill.
4 gills	= 1 pint.
2 pints	= 1 quart.
4 quarts, or 277·274 cubic inches	= 1 gallon.

CORN MEASURE.

2 gallons	= 1 peck.
4 pecks, or 2218·192 cubic inches	= 1 bushel.
8 bushels	= 1 quarter.
5 quarters	= 1 load.

AVOIRDUPOIS WEIGHT.

27·34375 troy grains	= 1 drachm.
16 drachms	= 1 ounce.
16 ounces	= 1 pound.
28 pounds	= 1 quarter.
4 quarters, or 112 pounds	= 1 cwt.
20 cwts., or 2240 pounds	= 1 ton.

Common Gravity of Fresh Water.

1 cubic inch	=	·03617 pound
12 cubic inches	=	·434 "
1 cubic foot	=	62·5 pounds.
1·8 cubic feet	=	1 cwt.
35·84 cubic feet	=	1 ton.
1 cylindrical inch	=	·02842 pound
12 " inches	=	·341 "
1 " foot	=	49·1 pounds.
2·282 " feet	=	1 cwt.
45·64 " feet	=	1 ton.
1 cubic foot	=	6·25 imp. galls.
1 cylindrical foot	=	5 imp. gallons
11·2 imperial gallons	=	1 cwt.
224 " "	=	1 ton.
1 cubic foot of sea-water	=	64·2 pounds.
34·9 cubic feet of do.	=	1 ton.

Approximate Weights for Practical Purposes.

	Specific gravities.	Weight of a cubic inch in pounds.	Weight of a cylindrical inch in pounds.
Iron, cast . .	7207	·2608	·2048
Iron, bar . .	7700	·2785	·2187
Steel	7833	·2833	·2225
Copper . . .	8878	·3211	·2522
Brass, cast . .	8396	·3037	·2385
Zinc, common .	7028	·2542	·1996
Lead	11352	·4106	·3225
Tin, cast . .	7291	·2637	·2071

To compare Degrees of Temperature indicated by different Thermometers.

Rule 1.—Multiply degrees of Centigrade by 9 and divide by 5; or multiply degrees of Reaumur by 9 and divide by 4. Add 32 to the quotient in either case, and the sum is degrees of Fahrenheit.

Rule 2.—From degrees of Fahrenheit subtract 32, multiply the remainder by 5, and divide by 9 for degrees of Centigrade; or multiply by 4 and divide by 9 for degrees of Reaumur.

Tables deduced from Experiments on Iron and Copper Plates for Steam Boilers, by the Franklin Institute, Philadelphia.

Iron boiler plate was found to increase in tenacity as its temperature was raised, until it reached a temperature of 550° above the freezing point, at which point its tenacity began to diminish. The following table exhibits the cohesive strength at different temperatures:—

At	32° to 80°	the tenacity was	= 56,000 lbs., or one-seventh below its maximum.
At	570°	" "	= 66,500 lbs., the maximum
At	720°	" "	= 55,000 lbs., the same nearly as at 32°.
At	1050°	" "	= 32,000 lbs., nearly one-half of the maximum.
At	1240°	" "	= 22,000 lbs., nearly one-third of the maximum.
At	1317°	" "	= 9,000 lbs., nearly one-seventh of the maximum.

At 3000° iron becomes fluid.

Note.—The accidental overheating of a boiler was found to reduce its strength from 65,000 pounds to 45,000 per square inch.

Table showing the Diminution of Strength of Copper Boiler Plates by additions to the temperature, the cohesion at 32° *being* 32,800 *pounds per square inch.*

No.	Temperature above 32°.	Diminution of strength.	No.	Temperature above 32°.	Diminution of strength.
1	90°	0·0175	9	660°	0·3425
2	180	0·0540	10	769	0·4398
3	270	0·0926	11	812	0·4944
4	360	0·1513	12	880	0·5581
5	450	0·2046	13	984	0·6691
6	460	0·2133	14	000	0·6741
7	513	0·2446	15	1200	0·8861
8	529	0·2558	16	1300	1·0000

Table of Experiments on Iron Boiler Plate at high temperatures, the mean maximum tenacity being at 550°=65,000 *pounds per square inch.*

Temperature observed.	Diminution of tenacity observed.	Temperature observed.	Diminution of tenacity observed.
550°	0·0000	824°	0·2010
570	0·0869	932	0·3324
596	0·0899	947	0·3593
600	0·0964	1030	0·4478
630	0·1047	1111	0·5514
652	0·1155	1155	0·6000
722	0·1436	1159	0·6011
732	0·1491	1187	0·6352
734	0·1535	1237	0·6622
766	0·1589	1245	0·6715
770	0·1627	1317	0·7001

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